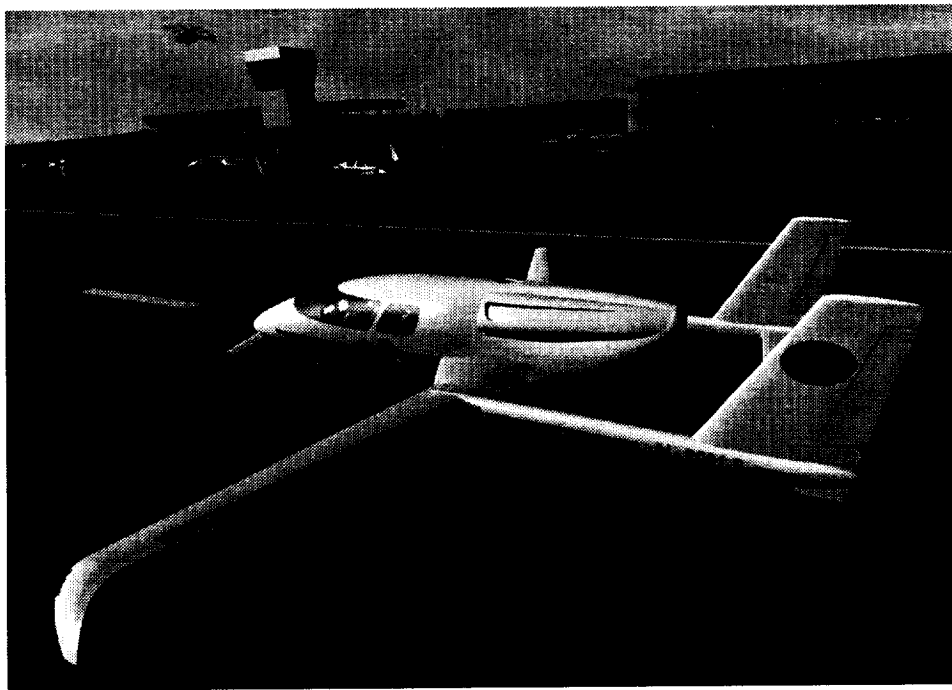
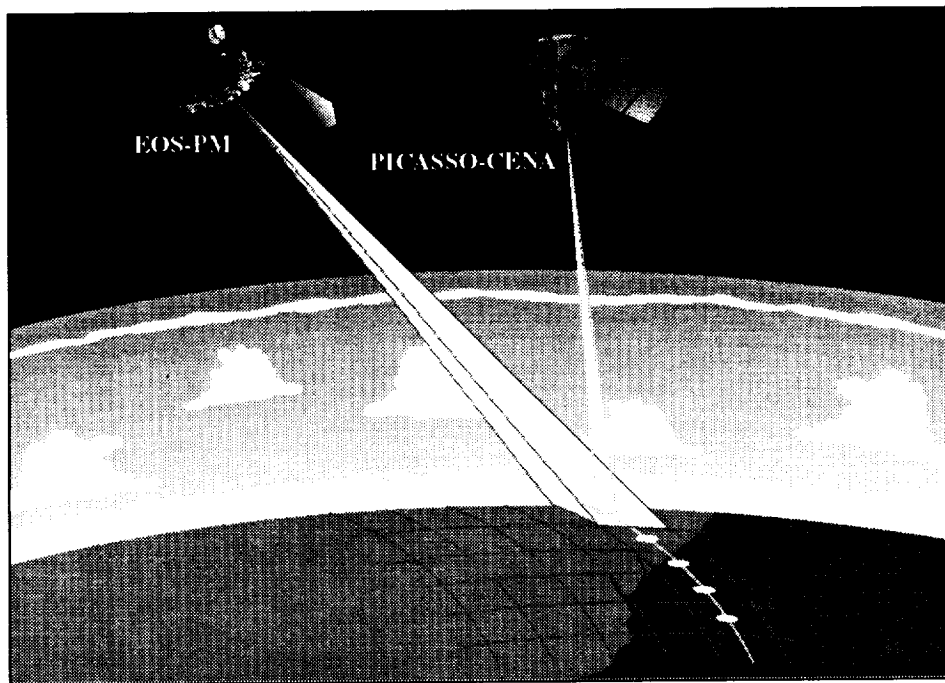


NASA Langley Highlights



1998

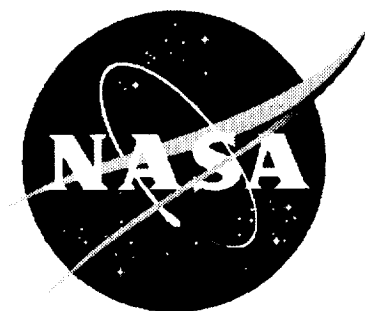
NASA/TM-1999-209363

**National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23681-2199**

Shown on the top half of the cover is a schematic of the PICASSO-CENA satellite providing measurements of the aerosol and cloud structure and their optical and physical properties. NASA Langley and Hampton University jointly proposed the mission in partnership with the French Space Agency CNES for NASA's Earth System Science Pathfinder program. It will be launched in 2003. For more information, contact David Winker at d.m.winker@larc.nasa.gov.

Shown on the bottom half of the cover is the design for a future general aviation aircraft developed as part of the Small Aircraft Transportation System (SATS). SATS has a major objective to "enable doorstep-to-destination travel at four times the speed of highways to 25 percent of the Nation's suburban, rural, and remote communities in 10 years and more than 90 percent in 25 years." For more information, contact Bruce Holmes at b.j.holmes@larc.nasa.gov.

NASA Langley Highlights



1998

NASA/TM-1999-209363

**National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23681-2199**

Foreword

The NASA missions assigned to Langley Research Center are Airframe Systems and Atmospheric Sciences. Langley is also designated the Agency's Center of Excellence for Structures and Materials in recognition of its long history of research into innovative composites, polymers, metallics, and structures for aircraft and spacecraft. The Airframe Systems mission incorporates a variety of aeronautical areas such as aerodynamics, aerothermodynamics, acoustics, aircraft mission and system analysis, hypersonic airbreathing propulsion, airborne system and crew station design and integration, and structures and materials. Virtually every American aircraft and a number of spacecraft in operation today incorporate some technology that developed from research originating at NASA Langley. The Center's Lead Program assignments in the NASA Aero-Space Technology Enterprise assure a continuation of Langley's historic leadership role in national aeronautics research.

Langley's Atmospheric Sciences program began in the 1970's to study potential changes to the atmospheric environment associated with operating proposed advanced aircraft. The program has become a world-class producer of innovative research and technology to advance knowledge of atmospheric radiation, chemistry, and dynamics for understanding global change. In close collaboration with the NASA Earth Science Enterprise and academia, Langley scientists identify critical atmospheric science issues for research and provide key contributions to national and international assessments of the environment. The resulting advanced technology, remote sensing techniques, atmospheric data sets, and scientific information are widely used by the scientific, policy and educational communities.

Langley's mission is accomplished by performing innovative research relevant to national needs and Agency goals, transferring technology to users in a timely manner, and providing development support to other United States Government Agencies, industry, other NASA Centers, the educational community, and the local community. This report contains highlights of some of the major accomplishments and applications that have been made by Langley researchers and by our university and industry colleagues during the past year. The highlights illustrate the broad range of research and technology activities carried out by NASA Langley Research Center and the contributions of this work toward maintaining United States' leadership in aeronautics and space research. A color electronic version of this report is available at URL <http://larcpubs.larc.nasa.gov/randt/1998/>.

For further information about the report, contact Dennis Bushnell, Senior Scientist, Mail Stop 110, NASA Langley Research Center, Hampton, Virginia 23681-2199, (757)-864-8987, e-mail address: d.m.bushnell@larc.nasa.gov.



Dr. Jeremiah F. Creedon
Director

Availability Information

The accomplishments in this report are grouped into four categories based on NASA's Strategic Enterprises, including Aero-Space Technology; Earth Science; Space Science; and Human Exploration and Development of Space. The Aero-Space Technology Enterprise is further divided into three "Pillars," which are Global Civil Aviation; Revolutionary Technology Leaps; and Access to Space.

The contributions have been carefully screened to avoid disclosure of any export-controlled information; any company-proprietary information or any other "enabling" data from joint NASA-industry programs such as those under Space Act Agreements, focused programs, etc.; or any potentially patentable inventions for which patents have not already been granted.

For additional information, call or E-mail the point-of-contact (POC) that is identified with each highlight. Only a limited number of black and white hard copies of this report have been printed, because the full report is available in color on the internet and can be downloaded from the NASA Langley Highlight Report web page at <http://larcpubs.larc.nasa.gov/randt/1998/>.

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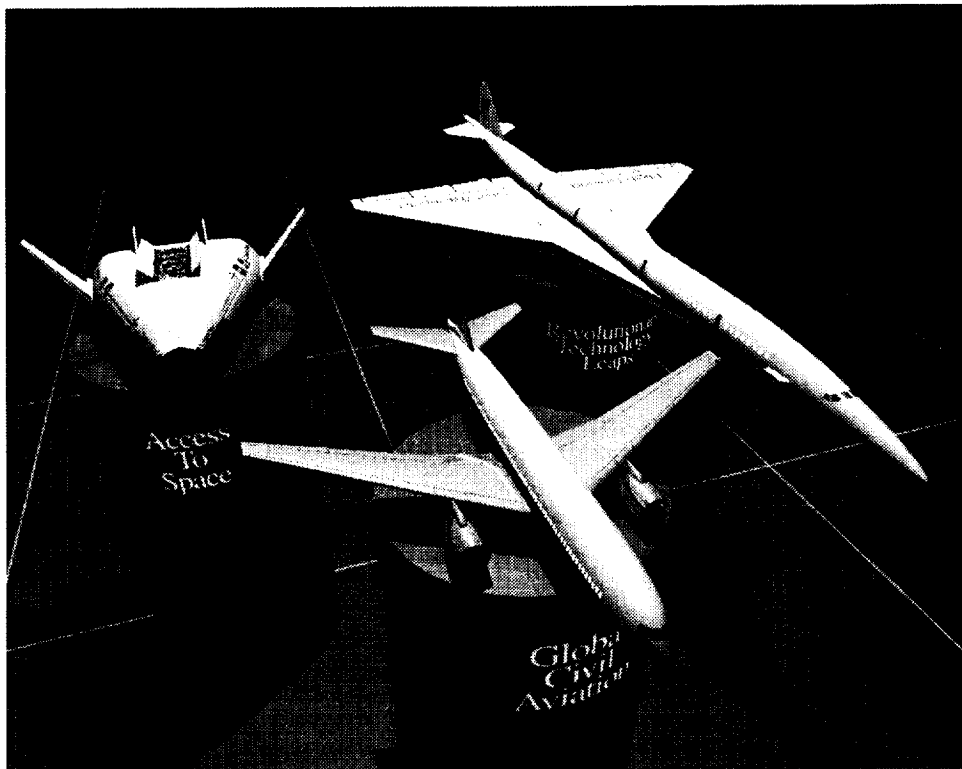
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Aero-Space Technology Enterprise



Three Pillars for Success

Pillar One: Global Civil Aviation

Pillar Two: Revolutionary Technology Leaps

Pillar Three: Access to Space

Mission

Research and technology play a vital role in ensuring the safety, environmental compatibility, and productivity of the air transportation system and in enhancing the economic health and national security of the Nation. However, numerous factors, including growth in air traffic, increasingly demanding international environmental standards, an aging aircraft fleet, aggressive foreign competition, and launch costs that impede affordable access and utilization of space, represent formidable challenges to the Nation.

The mission of the Aero-Space Technology Enterprise is to pioneer the identification, development, verification, transfer, application, and commercialization of high-payoff aeronautics and space transportation technologies. Through its research and technology accomplishments, the Enterprise promotes economic growth and national security through a safe, efficient national aviation system and affordable, reliable space transportation. The plans and goals of this Enterprise directly support national policy in both aeronautics and space, documented in "Goals for a National Partnership in Aeronautics Research and Technology" and "National Space Transportation Policy." The Enterprise works in alliance with its aeronautics and space transportation customers, including U.S. industry, the university community, the Department of Defense (DoD), the Federal Aviation Administration (FAA), and the other NASA Enterprises, to ensure that national investments in aeronautics and space transportation technology are effectively defined and coordinated and the NASA's technology products and services add value, are timely, and have been developed to the level at which the users can confidently make decisions regarding the application of those technologies. The goals given in this report were in effect during 1998.

Goals

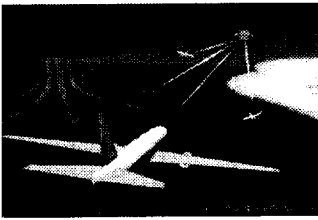
The Enterprise had three major technology goals supported by ten enabling technology objectives.

Technology Goals

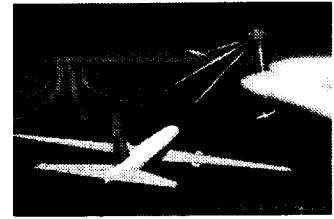
Global Civil Aviation—Enable U.S. leadership in global civil aviation through safer, cleaner, quieter, and more affordable air travel.

Revolutionary Technology Leaps—Revolutionize air travel and the way in which aircraft are designed, built, and operated.

Access to Space—Enable the full commercial potential of space and expansion of space research and exploration.



Pillar One: Global Civil Aviation



NASA's 1998 objectives for improving air transportation system safety, affordability, and environmental compatibility included technology for a ten-fold improvement in the safety of flight, a 50% reduction in the cost of air travel, and equally aggressive reductions in aircraft noise and emissions over the next 20 years.

Integrally Stiffened Airframe Structures

For aircraft manufacturers, a major challenge is to reverse the trend of increasing aircraft ownership and operating costs. The goal of the Integral Airframe Structures (IAS) Project is to develop the advanced technologies that may be used by U.S. aircraft industry to enable significant cost reductions in manufacturing integral metallic aircraft fuselage structure. Research was done to build and test paradigm-breaking integral stiffened fuselage structure that was less expensive to manufacture, equal in structural performance, and

weight equivalent of today's current built-up structure. The panel shown in figure 1 arrested a longitudinal two bay crack while supporting limit load, a critical test to demonstrate equivalent structural performance. Cost study results have indicated a recurring cost savings of 61% by high speed machining structure from aluminum plate as compared to conventional built-up structure. Part counts dropped from 78 individual parts (not including rivets) on the baseline panel to just 7 on the integrally stiffened panel, clearly showing a significant part count reduction. The integral structural panel was weight neutral.

(Joan Funk, j.g.funk@larc.nasa.gov, 757-864-3092)



Figure 1. The uppermost figure shows an integrally stiffened fuselage panel that was machined from 7475 plate. The lower figure shows the same panel mounted in the Boeing pressure box test facility prior to undergoing a 2-Bay Fracture Test.

NASA Airframe Structural Integrity Program

In April 1988, an Aloha Airlines Boeing 737-200 experienced an in-flight structural failure in which a large section of the upper fuselage tore open and left the aircraft. The failure resulted from multiple site damage (MSD) and corrosion. MSD is the link-up of small fatigue cracks extending from adjacent rivet holes (i.e., widespread fatigue damage, or WFD) in a fuselage longitudinal lap joint. The accident focused international attention on the problems of operating an aging commercial fleet. Today, the average age of the world's operating fleet is over 12 years old, and approximately 1000 airplanes, or one-fourth of the operating fleet, are more than 20 years old. More than 500 of those airplanes are 25 years or older, and some airlines are planning to keep their airplanes flying past 30 years. This trend, simply based on the lower cost of inspection and maintenance versus the cost of acquiring new airplanes, will continue in the future as airlines attempt to attain positive balance sheets. In order to safely and economically extend the life of high time airplanes in the commercial jet transport fleet, NASA initiated the NASA Airframe Structural Integrity Program (NASIP) in 1990. This program was jointly conceived and planned with the FAA. In 1992 NASIP became an element of NASA's Advanced Subsonic Technology (AST) Program and in FY 1998, the element was completed meeting or exceeding all program goals.

The overall goal of the NASIP program is to develop advanced technology that may be used by the U. S. airline operators and aircraft manufacturers to safely and economically extend the life of high time airplanes in the commercial jet transport fleet. The NASIP program directly contributes to NASA's Safety Goal of reducing the accident rate by a factor of 5 within 10 years and by a factor of 10 within 20 years. The technology development performed via NASIP has focused on advanced methodologies to predict in-service inspection intervals through a combination of advanced nondestructive evaluation (NDE) techniques for determining disbonds corrosion and cracks, and structural integrity analysis methodologies for predicting fatigue crack growth and residual strength. New analysis methodologies, in the form of structural integrity analysis computer codes have been developed, experimentally verified, and are in use in the airframe industry. New NDE techniques have been developed, prototype systems have been field tested under real life service conditions, and the technologies have been licensed and commercialized by the NDE instrument manufacturing community.

The program has made major contributions to advancing the state of the art. In summary, the rigor of elastic-plastic fracture mechanics coupled with nonlinear structural analysis capable of modeling real-world structural details (i.e., fasteners, stiffeners, frames, joints, etc.) provides predictive capability that had not been previously available, but is critical for assessing the phenomenon of WFD in aging airframe structure. Also, the NDE techniques developed provide the capability for significantly decreasing the time and cost of inspections, and have provided, in some cases, factors of 3-4 better resolution. This increased resolution provides the ability to detect cracks nondestructively that before could only be found through destructive tear-down inspections.

Significant originality and innovation have been incorporated into the technology development, leading to the success of the program. Rigorous, elastic-plastic fracture mechanics models have been incorporated into nonlinear, large scale structural analysis codes to accurately predict the behavior on a local level in the vicinity of a crack and to predict its influence on the global level of a complicated, real-world structural component. These analyses have then been verified with innovative test techniques that subject actual structural components to combined loads that are representative of real in-service conditions. New, innovative NDE concepts have been developed, such as the self-nulling eddy current probe (figure 2), that have led to significant increases in reliability and resolution of existing commercial instruments.

The program has been structured to provide a level of accomplishment and technical performance that will lead to rapid transition and insertion into the worldwide

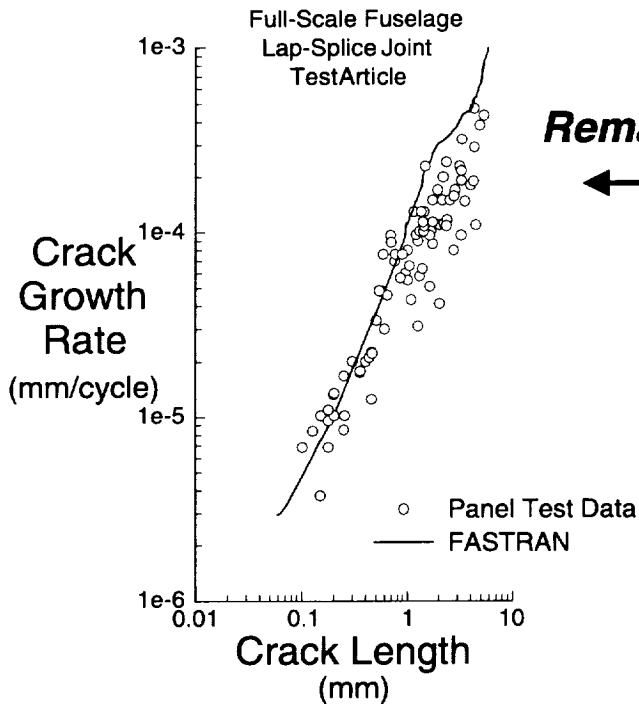


Figure 2. Self-nulling eddy current probe

Inspection Intervals

FASTRAN

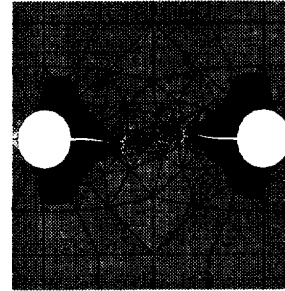
Fatigue Crack Growth Life Prediction



Residual Strength

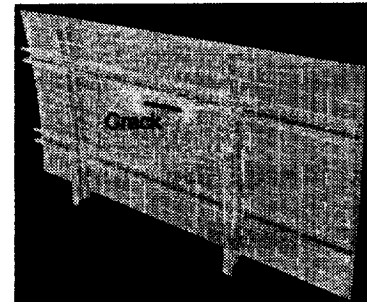
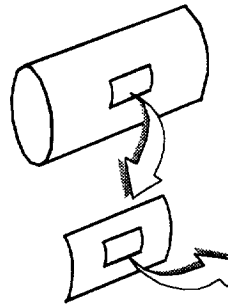
FRANC2D

Fracture Mechanics Analysis



FRANC3D/STAGS

Global/Local Structural Analysis



Remaining Life



Figure 3. Specialized engineering analysis tools quantitatively evaluate inspection findings by computing inspection intervals and residual strength

aircraft community. The analysis codes have been verified from the coupon level all the way up to actual structural components subjected to combined loading representative of in-service conditions. The NDE techniques and prototype instruments have been field tested at actual aircraft repair and maintenance facilities. Tests have also been conducted at the FAA's NDE Validation Center, where the rotating head eddy current probe (for detecting cracks under rivet heads) demonstrated the best performance of any system tested there or any system commercially available, with better resolution by factors of 3 to 4.

Perhaps the strongest indication of the success of the program has been the technology transfer that has already occurred and that is expected to occur in the program. The structural analysis methodology codes are already in use by industry. An Engineering Handbook that documents the methodology and an on-line database of all of the experimental data are in preparation. The CTOA (crack tip opening angle) fracture criterion has been incorporated into the commercially

available ABAQUS finite element structural analysis code. The FASTRAN computer code for fatigue crack growth (see figure 3) has been incorporated into NASGRO (NASA Crack Growth Analysis), the analysis maintained at Johnson Space Center for determining fracture characteristics of Shuttle payloads. Two of the NDE prototype instruments (eddy current probes) have been licensed and commercialized, and a third (thermal imaging system) has been licensed for possible future commercialization.

(David E. Bowles, d.e.bowles@larc.nasa.gov, 757-864-1919)

First Computational Prediction of Flap-Edge Airframe Noise

The current state of the art in airframe noise prediction utilizes methods that are heavily based on empiricism. The current research in airframe noise prediction determines the fundamental mechanisms associated with airframe noise generation and develops a

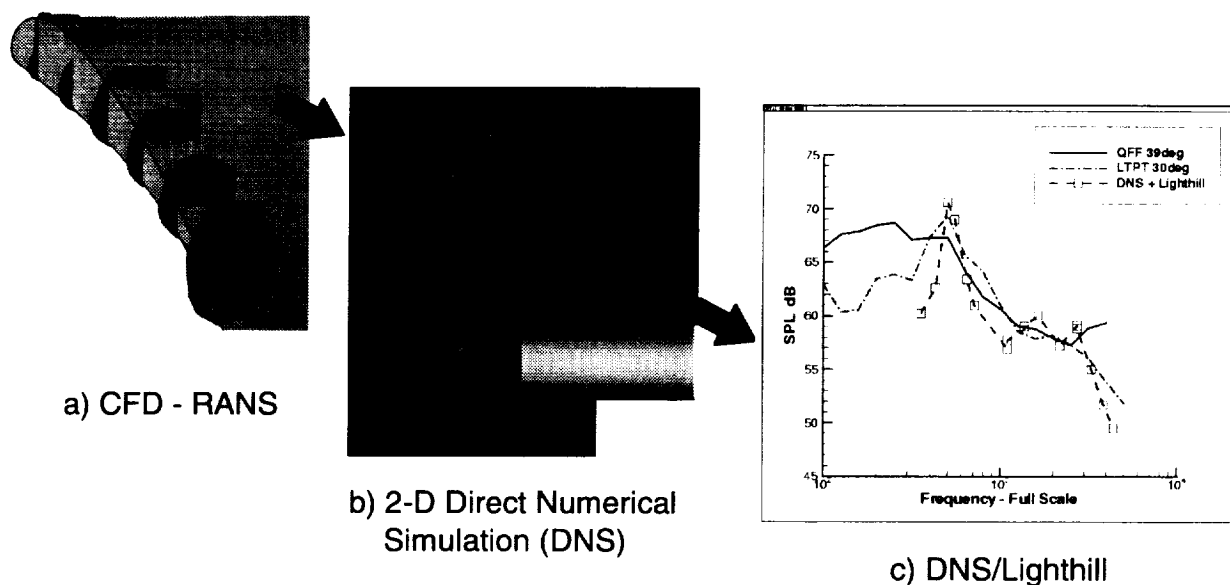


Figure 4. Use of numerical/experimental simulations to predict flap side-edge airframe noise:

a) Steady flow computations surrounding flap-side edge

b) Unsteady computation of instabilities which generate flap-edge noise

c) Direct Numerical Simulation coupled with the Lighthill Acoustic Analogy for farfield noise; comparison with experiments in good agreement

computational noise prediction tool based on fundamental principles of physics associated with these mechanisms (i.e., no empiricism!). The current approach uses a Reynolds Averaged Navier Stokes (RANS) computational fluid dynamics code to compute the mean flow about the noise generating structure (i.e., a flap side edge for this study). From this analysis, critical flow mechanisms are identified for noise source generation. Then a detailed source computation of these critical flow mechanisms is made using Direct Numerical Simulation (DNS) to compute the fluctuations associated with the flap-edge noise generation.

The results are then coupled with a far-field noise propagation method (the Lighthill Acoustic Analogy) to compute the noise source characteristics. The predicted results compared well with experimental measurements (figure 4), and were successfully used to develop a noise reduction concept in the Advanced Subsonic Technology program. Through advanced tools and measurements, fundamental understanding and prediction of noise production can lead to advanced physics-based noise reduction concepts.

(Long Yip, l.p.yip@larc.nasa.gov, 757-864-3866)

Flap Edge Airframe Noise Reduction

One of NASA's 10-year goals is to develop technology to reduce the noise impact from aircraft such that communities in the surrounding areas of airports hear one half of the noise that they heard in 1997. In technical terms, this means a 10 decibel (dB) reduction in noise. The Noise Reduction Element of the Advanced Subsonic Technology (AST) Program played a key role in providing the technologies to achieve the 10 dB noise reduction goal. This amount of noise reduction is similar to the difference in traffic noise from a road with heavy traffic and the same road with light traffic. The source of the noise from today's airplanes is primarily from the jet engines, but noise from the airplane itself, particularly during approach, is a strong contributor to the overall noise impact.

During landing, when airplanes are relatively close to the ground, the airframe noise from the flaps, slats, and landing gear on today's airplanes almost matches the level of engine noise. In future airplanes, the airframe noise will be equal to engine noise not only during landing but also during take-off. However, airframe noise, like engine noise, can be controlled and reduced with advanced noise reduction technology.

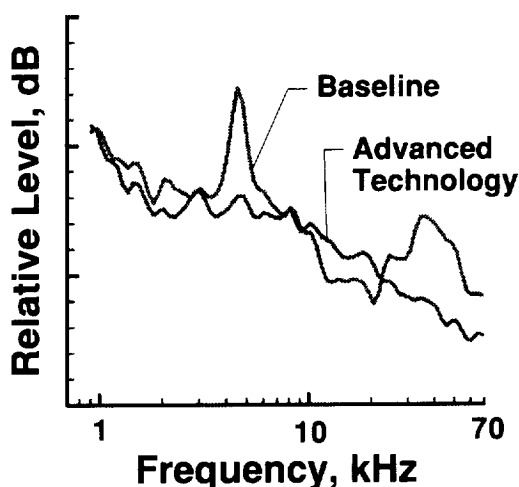


Figure 5. Microphone array results (1/12 octave spectra) treated with low noise advanced technology

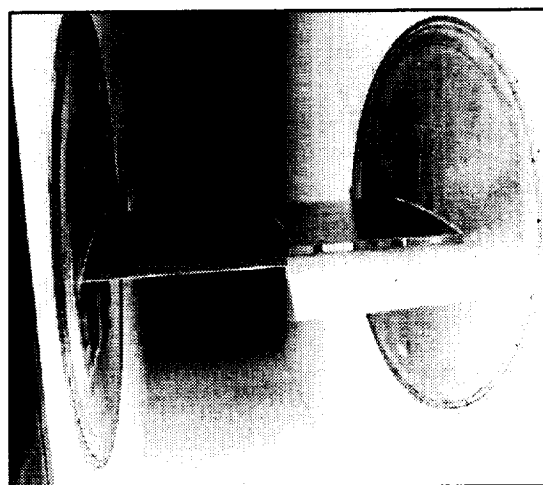


Figure 6. Baseline model (Mach 0.2, Reynolds number of 7.2M) in Low Turbulence Pressure Tunnel (LTPT)

An accomplishment within the AST Noise Reduction Element is the demonstration of technology to reduce flap noise, one of the three main airframe noise sources, by 4 dB. This was accomplished by NASA researchers in partnership with industry, academia, and the FAA. Results of a series of wind tunnel experiments, guided by newly developed noise and flow prediction models, successfully demonstrated significant noise reductions could be obtained with innovative flap-edge devices. Research on technologies to reduce slat and gear noise, the other main airframe noise sources, is ongoing. These technologies for reducing flap noise significantly contribute to achieving the program's overall goal of a 4 dB reduction in airframe noise.

The demonstrated flap noise reduction technologies involved several of NASA's and industry's wind tunnels, each one for its unique performance capabilities. The results illustrated in figure 5 are from a test performed in Langley's Low Turbulence Pressure Tunnel. A microphone array was employed in this hard-walled facility to measure and localize the sound coming from the high lift wing model shown in figure 6. This wind tunnel is run at pressures greater than atmospheric to more closely simulate full-scale flight conditions or Reynolds number. Advanced aerodynamic flow models were used to optimize noise reduction concepts for three different dominant airframe noise sources discovered for this wing model.

(William L. Willshire, w.l.willshire@larc.nasa.gov, 757-864-1919)

Aviation System Analysis Capability

The Systems Evaluation Element of the Advanced Subsonic Technology (AST) Program aimed to reduce air travel costs by developing the methodologies that assess the impact of alternative emerging civil aeronautics technologies on the integrated aviation system. A major milestone in the System Evaluation element was the delivery of the Aviation System Analysis Capability by the Logistics Management Institute, a non-profit organization, in McLean, Virginia. Among the many types of specialized aviation-related analyses which can be conducted are community noise impacts, national economic impacts, and safety and operational analyses. It is the first computerized analysis system that uses "intelligent interfaces" to link models and databases at geographically dispersed sites to enable highly automated analyses and data queries via the Internet (figure 7). NASA and the aviation industry use ASAC to guide technology investment strategies for current and future aeronautics programs relative to cost effective investments. ASAC also provides a single focal point linking NASA, FAA, airlines, and aviation manufacturers together and facilitates communication between these aviation-related organizations. The capability ASAC provides will be critical in assessing the future aviation system.

(Robert E. Yackovetsky, r.e.yackovetsky@larc.nasa.gov, 757-864-1919)

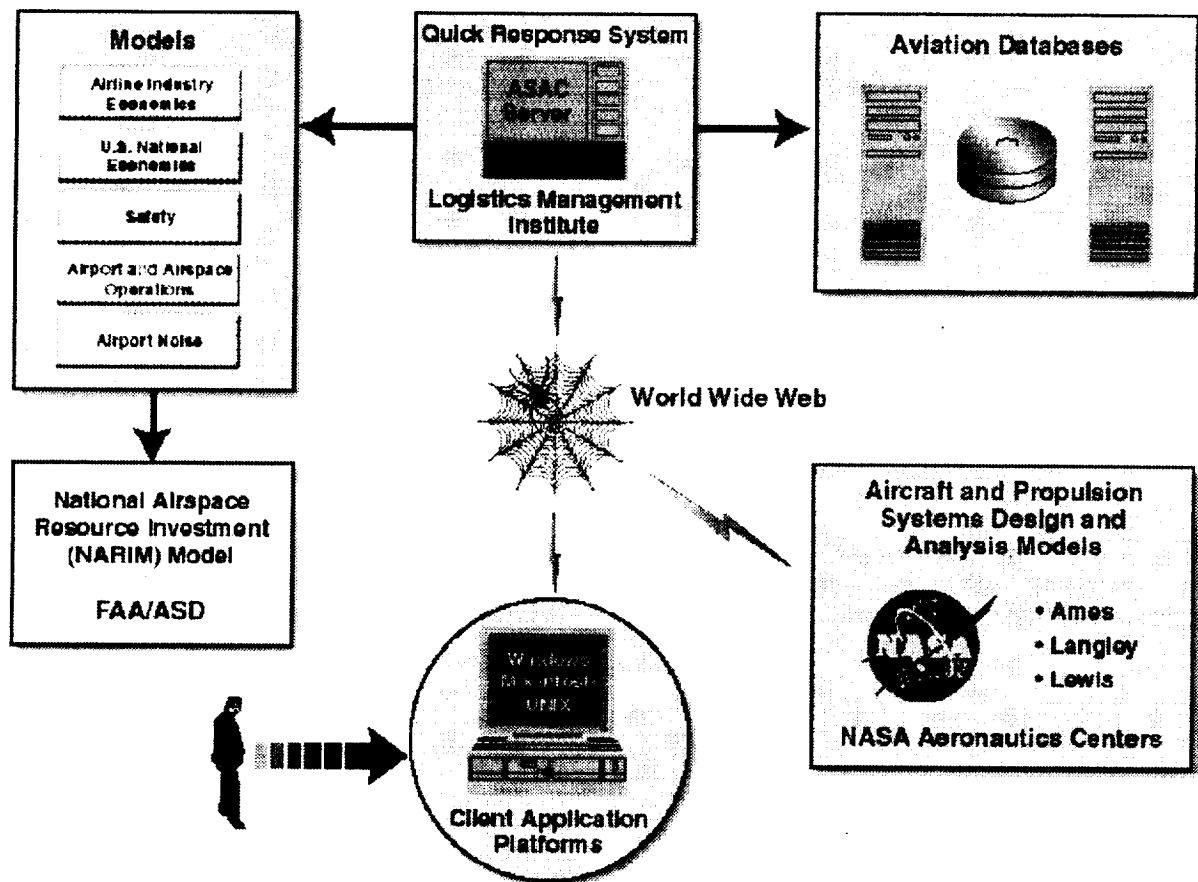


Figure 7. ASAC uses "Intelligent Interfaces" to link models and databases at geographically dispersed sites to enable highly automated analyses and data queries via the Internet.

Radio Frequency Controlled Digital Acoustic Measurement System

A Radio Frequency (RF) controlled digital acoustic measurement system (RFDAM) has been developed to support the Global Civil Aviation pillar goal of reducing the perceived noise levels of future aircraft by a factor of two from today's subsonic aircraft within 10 years, and by a factor of four within 20 years. This system provides the unique capability of taking high quality acoustic measurements over a 30 square mile area. Researchers at NASA Langley have been engaged in acoustic research directed toward understanding and reducing noise generated by aerospace vehicles. The RFDAM will allow the acoustic researchers to look at acoustic footprints for an area that is 10 times larger than footprints provided by the current acoustic measurement system. In addition, the RFDAM will increase bandwidth of the system by a factor of four to 100KHz.



Figure 8. Remote acoustic system setup during successful test at False Cape State Park.

The system consists of a base station van where the operator can control and monitor all remote stations via an RF link and LabView-based user interface and up to thirty remote microphone systems. Each of the remote microphone systems has its own Internet Protocol (i.p.) address to allow it to be accessed from the internet in future system upgrades. Basic operational commands are sent to the remote microphone systems to: activate data acquisition and storage; send back samples of data to the base station; monitor the health of the system; and take inputs from the auxiliary devices such as Weather data, GPS time code and position.

Data obtained from the RFDAM (figure 8) is expected to be used by acoustic researchers from NASA Langley, other NASA centers, Bell Helicopter, McDonnell Douglas, FAA, and other government and aerospace agencies that are working to meet the previously mentioned goal in noise reduction.

(Kenneth Wright, k.d.wright@larc.nasa.gov, 757-864-4665)

Shear Stress Measurement Using Ferroelectric Liquid Crystals

A ferroelectric liquid crystal (FLC) film applied on a transparent surface has been demonstrated to alter the amount of light transmitted through it in response to shear stress. When used in the reflective mode with a light source and camera, FLCs could potentially provide both qualitative and quantitative images of shear stress levels over an entire wing or other aerodynamic surface. Such information from wind tunnel and flight tests can be used by aircraft designers to minimize drag and improve fuel efficiency. This will both reduce emissions and lower the cost of air travel.

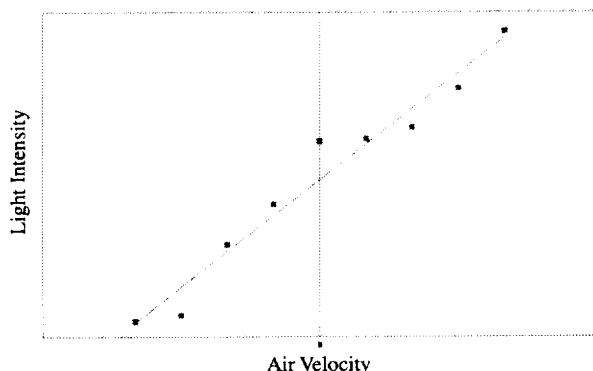


Figure 9. Intensity of light transmitted through FLC film as a function of air velocity

A thin film of FLCs was painted on a glass surface using a solvent and allowed to dry with an initial molecular orientation with respect to the surface. When subjected to shear stress from a jet of air blown across the surface the FLC molecules were reoriented, altering the amount of polarized light shining through them as recorded by a camera. The crystals resumed their initial orientation when the air jet was removed. The intensity of the light can thus be related to the force and direction of the air along the surface, as shown in figure 9.

FLCs can operate over a wider temperature range, are faster responding, and adhere better to substrates than conventional liquid crystals that change color under shear stress. Intensity-altering liquid crystal films also require less sophisticated and expensive imaging equipment.

(Danny R. Sprinkle, d.r.sprinkle@larc.nasa.gov, 757-864-4761)

Cloud Increases from Contrails

Commercial and military jet aircraft operate in the upper troposphere, a portion of the atmosphere that is very clean compared to the boundary layer where most air pollutants generally form and persist. As part of the effort to monitor anthropogenic effects on the environment, the Subsonic Assessment (SASS) Program, part of the NASA Atmospheric Effects of Aircraft Program (AEAP), is examining the impact of increased air travel on the troposphere and lower stratosphere. Through their exhaust, aircraft produce a variety of gaseous compounds in addition to water vapor and aerosols. One of the most visible and, perhaps, most important effects of high-altitude air traffic is the production of condensation trails or contrails. In many instances, these artificial clouds are linear streaks in the sky that may rapidly dissipate or, in the proper conditions, persist and grow. If they persist, contrails will act like natural cirrus clouds by reflecting solar radiation causing cooling or trapping infrared radiation from the surface causing a greenhouse-type warming. The net effect, warming or cooling, depends on many factors such as lifetime, thickness, and the size of cloud's particles. Thus, it is important to measure these aspects of contrails.

Because contrails form at high altitudes, they tend to move at high speeds making them difficult to track. They also tend to form in the vicinity of natural cirrus so distinguishing them from natural cirrus is difficult. During the spring of 1996, SASS sponsored the Subsonic aircraft: Contrail and Cloud Effects Special Study (SUCCESS) field experiment over the western US.

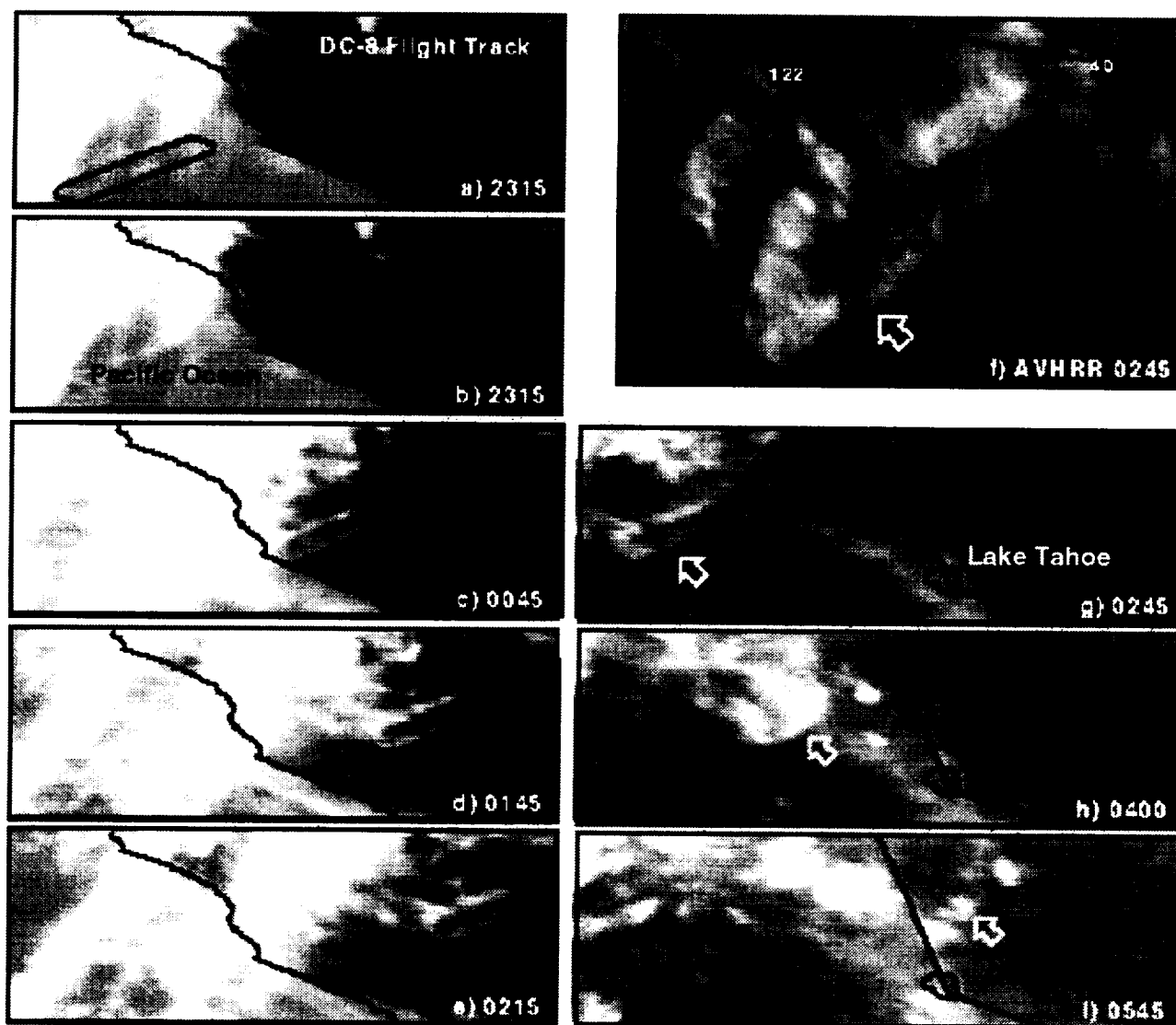


Figure 10. Development of oval contrail from DC-8 exhaust during May 12, 1996 SUCCESS flight off coast of California as observed in GOES 4 km Infrared images (a-d, g-i) and NOAA-12 AVHRR 1 km Infrared images (f).

During a May 12 SUCCESS flight off the coast of California, the NASA DC-8 produced a 100-km long oval-shaped contrail in clear air at an altitude of 10 km. This contrail quickly became visible in the 4-km resolution Geostationary Operational Environmental Satellite (GOES) imagery (figure 10). The contrail continued to grow and spread as it traveled across California before dissipating over the Sierra Nevada Mountains more than 5.5 hours after it first formed. Analyses of the GOES data taken every half hour reveal that it covered nearly 5,000 km² approximately 3 hours after it formed. Its particles grew from very small sizes to those similar to natural cirrus in a few hours. The cloud

was relatively thin. The contrail's oval shape facilitated the observation of its conversion to a cirrus cloud. A ground observer would have difficulty recognizing this cloud as a contrail. These results are the first to show the formation of a persistent contrail followed by its advection to a different area while it changed into an ordinary-looking cirrus cloud. Other examples of contrail persistence were observed in GOES imagery taken during SUCCESS. How often this process occurs and how much cloud cover is being generated by contrails remain important questions for continuing SASS research. It is clear, however, that contrails can have a significant effect on cloud cover.

(Patrick Minnis, p.minnis@larc.nasa.gov, 757-864-5671)

Airborne Lidar Measurements of Ozone and Aerosols During SONEX

The NASA Langley Airborne UV Differential Absorption Lidar (DIAL) system operated during the SONEX (Subsonic assessment Ozone and Nitrogen Experiment) mission to measure ozone and aerosols above and below the DC-8 aircraft in flights in and around the north Atlantic flight corridor. The primary objective of the UV DIAL measurements was to provide the chemical and meteorological context of the atmosphere sampled by the in situ instruments on the DC-8 in a study to determine the effect of airplane emissions on the composition and chemistry of the atmosphere. The ozone and aerosol distributions across the troposphere and into the lower stratosphere were routinely obtained by the UV DIAL system along

the DC-8 flight track during flights from bases in Bangor, Maine, and Shannon, Ireland, in October and November 1997. Ozone, aerosol, and cloud distributions were used in the characterization of the composition and meteorological conditions associated with each mission. The ozone data were used to define the variation in the height of the tropopause, and on occasion observations were made of aircraft contrails and tropospheric processes associated with enhanced ozone in the lower atmosphere and in continental plumes at large distances from land.

The UV DIAL measurements of ozone and aerosols across the troposphere and lower stratosphere showed the complex composition and dynamics of the atmosphere encountered on almost every SONEX mission. This complexity resulted primarily from the

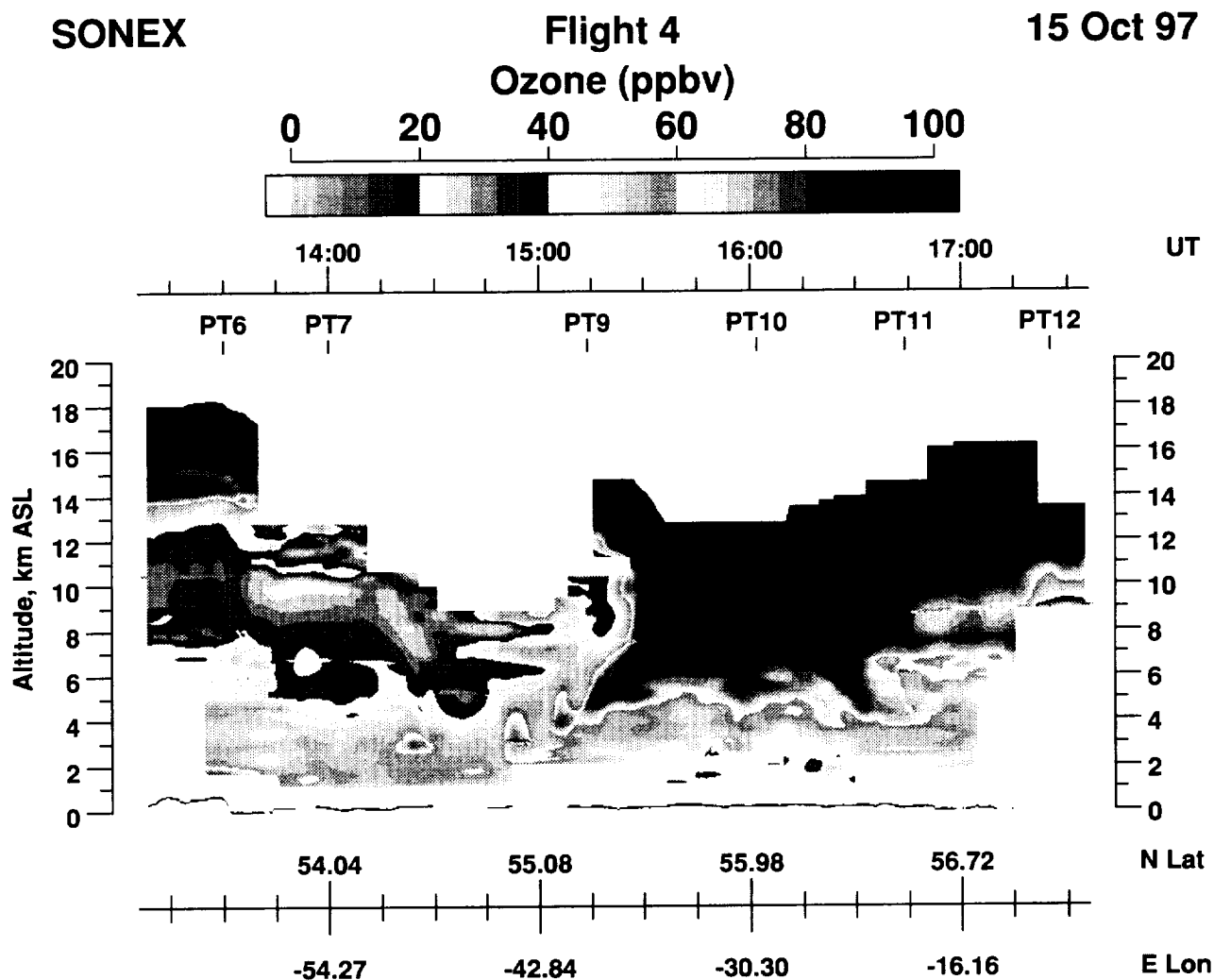


Figure 11. Airborne UV DIAL measurements of ozone on the flight from Bangor, Maine, to Shannon, Ireland, on October 15, 1997. (Color version is on report website.)

atmospheric variability introduced by the frequent presence of stratospheric intrusions and the associated large variability in tropopause heights along our flight tracks. The SONEX flight from Bangor to Shannon (see figure 11) on October 15, 1997, is a typical flight with a strong stratospheric intrusion. The combined zenith and nadir UV DIAL ozone data are shown for this flight. Near the U.S. and Canada, the tropopause height was near 14-km, and cirrus clouds were observed just below the tropopause. In the mid-troposphere (5–10 km) ozone values were in the range of 35–45 ppb, and there was a thin plume below 2 km with ozone in excess of 60 ppb (parts per billion), likely transported from urban/industrial regions to the south. As the flight progressed, a sharp decrease in the height of the tropopause was observed above the aircraft near 39W, 55N. Near 21W the tropopause height was observed rising again, and by 9W it was back up to about 12 km. In the lower troposphere, evidence of the stratospheric intrusion was seen as far west as 50W and down to as low as 2 km. The ozone concentrations about 2 km were enhanced in the lower troposphere across the Atlantic from 50W to at least 15W with background ozone levels increasing from 40–50-ppbv range to the 50–60-ppb range and higher in filaments associated with the intrusion.

Stratospheric intrusions were seen on ten out of fourteen SONEX missions. Most of these were seen in the latitude range from 37N to 52N and at all longitudes investigated during SONEX. The elevated ozone was often observed down to as low as 3 km above the surface. These observations indicate that the Atlantic flight corridor is a very dynamic region with considerable stratospheric influence in the troposphere. The UV DIAL measurements will be used to determine the large-scale air mass characteristics observed during SONEX and the representativeness of the in situ measurements made on the DC-8.

(Edward V. Browell, e.v.browell@larc.nasa.gov, 757-864-1273)

Characterization of Piezoelectric Actuators

Smart devices are being developed in the Morphing Project to enable self-adaptive flight for revolutionary improvements in efficiency and affordability. Application areas include flow control, active noise reduction, aeroelastic and structural control as well as health monitoring. Several flow control actuator concepts are considered, including seamless control effectors and a variety of synthetic jet and vortex generators. Actuators are modeled by continuous wing twist; thickness and camber changes and a linear panel method are

used to estimate stability derivatives by finite difference. The results show that for this novel fighter configuration, the simulated actuators can stabilize the initially laterally directionally unstable aircraft. Further developments will use nonlinear computational fluid dynamics (CFD) to verify the same benefits, using automatic differentiation to evaluate the stability derivatives. Flow control benefits of these novel actuators include low observability maneuvering, drag reduction, increased lift-to-drag ratio, multi-point performance optimization, and improved high angle of attack maneuverability.

(Jean-François Barthelemy, j.f.barthelemy@larc.nasa.gov, 757-864-2809)

Aerosol Emission Indices in Aircraft Plumes Encountered During SONEX

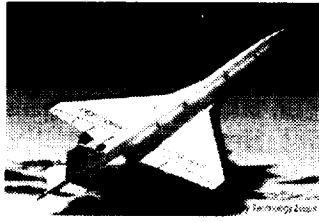
The SASS Ozone and NO_x Experiment (SONEX) was conducted aboard the NASA DC-8 aircraft during fall 1997 to assess the impact of aircraft emissions upon the chemistry and dynamics of the upper troposphere and lower stratosphere. The mission as discussed earlier in this report (figure 11), was staged primarily from Shannon, Ireland and Bangor Maine and included frequent sampling within air traffic corridors over the U.S and North Atlantic region. The aircraft payload, in addition to an extensive suite of in situ and remote chemical instruments, included fast response sensors for total condensation nuclei > 4 nm in diameter (ultrafine CN), total condensation nuclei >15 nm (fine CN), and nonvolatile condensation nuclei > 15 nm (nonvolatile CN) measurements. We have examined these measurements in conjunction with those of total reactive nitrogen species (NO_y) to identify aircraft plumes embedded within the upper troposphere over the SONEX study area. Several hundred plumes exhibiting ≥ 100 pptv enhancement in NO_y mixing ratio relative to background concentrations were observed. The plumes were typically a few hundred meters wide, exhibited high NO/NO_y ratios, were confined primarily to the regions around known flight corridors, and ranged from a few minutes to a few hours in age.

Because most of the plumes were too dilute to exhibit significant CO₂ enhancements (the standard combustion tracer used for relating emission parameters to kg of fuel burned), we have adopted the assumption that the source aircraft emitted a constant amount of NO₂ kg⁻¹ fuel burned in order to estimate aerosol emission indices (EIs) for all the well-defined plumes that were encountered. Statistics provided in a 1992 NASA publication (NASA Reference Publication

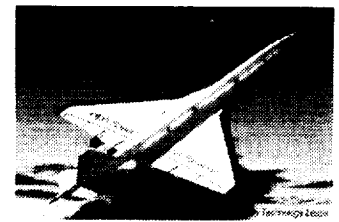
1400) indicate that commercial aircraft flying in the 8 to 12 km altitude range generate from 5 to 15 g NO₂ kg⁻¹ fuel burned and that the aircraft dominating the North American and North Atlantic routes emit a fuel-consumption weighted average of ~12 g NO₂ kg⁻¹ fuel burned. Using this value, we calculate aerosol EIs in terms of number of particles kg⁻¹ of fuel burned ranging from 5 to 300 x 10¹⁵ kg⁻¹ fuel burned for ultrafine CN; from 3 to 100 x 10¹⁵ for fine CN; and from 0.5 to 10 x 10¹⁵ for nonvolatile CN. The ultrafine and nonvolatile CN EIs are comparable to values determined by our group from aerosol and CO₂ observations in young (< 30 seconds old) commercial aircraft exhaust plumes which lends validity to the use of NO_y mea-

surements for estimating the EIs of aerosol species in dilute plumes. The fine CN EIs derived from the SONEX data were considerably larger than observed in fresh plumes, converging on the values of ultrafine EI in very dilute plume cases. Because the ultrafine EIs appeared to be invariant with plume age, this indicates that a large fraction of the ultrafine particles grow through accumulation of plume and background material to diameters exceeding 15 nm in a relatively short period of time. This approach provides a means of tracking the formation, growth, and change in properties of particles in aircraft engine exhaust plumes as they age and dilute with background air.

(Bruce Anderson, b.j.anderson@larc.nasa.gov, 757-864-5850)



Pillar Two: Revolutionary Technology Leaps



NASA will pioneer high-risk technology for revolutionizing air travel and the way in which aircraft are designed, built, and operated. Reducing overseas travel time by 50%, expanding the general aviation market, and decreasing aircraft concept-to-certification cycle time by 50% were the technology goals.

General Aviation Cockpit Technologies

In 1994, NASA, the FAA, the U.S. general aviation industry, and academia formed a unique partnership, the Advanced General Aviation Transport Experiments (AGATE) Consortium, to revitalize the general aviation industry in response to the severely declining U.S. general aviation market. This decline included significant decreases in small aircraft deliveries, general aviation fleet size, flight hours, public use airports, pilot population, and student pilot new starts. At its peak in 1978, the U.S. general aviation industry delivered 14,398 aircraft. In 1994, the number of aircraft had fallen to an all-time low of 444. AGATE underpins the joint venture by government and industry to revitalize U.S. general aviation and establish the basis for sustained growth into the next century. The AGATE Consortium provides a new way of doing business to facilitate rapid development and commercialization of emerging technologies.

The General Aviation Element of the Advanced Subsonic Technology Program was the focal point of NASA's effort to revitalize U.S. general aviation and it directly contributes to the goal of general aviation industry revitalization. A systems approach has resulted in progress toward this goal by addressing all aspects of the forces of decline: vehicles, users, and infrastructure.

Since early 1998, a Beech Bonanza F33C owned and modified by Raytheon Aircraft has been serving as an "integration platform" test bed for validation experiments of new technologies being developed by the AGATE Team. The experiments have resulted in the first successful combination of a number of breakthrough technologies on a single aircraft. Flight systems technology developments have included graphical, integrated, intuitive pilot displays and advanced avionics system architecture (figure 12) for revolutionizing general aviation cockpit information retrieval, processing, and display. Flightpath guidance information

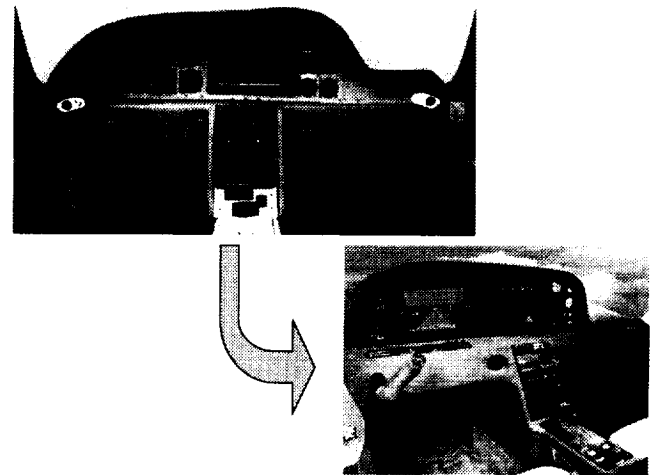


Figure 12. General Aviation Avionics System Architecture.

displayed through flat panel displays in the cockpit provides a "Highway in the Sky" presentation developed from a NASA concept that gives an intuitive 3-D presentation of the flight path and replaces the conventional cockpit displays. Integrated graphical weather, terrain, and traffic data provide simplified situational awareness. The information rich environment created by these technologies allows the pilot to focus on critical decision making information rather than on reducing data, which results in a significant impact on safety, reliability and ease of use.

Dramatic changes in the training procedures of general aviation pilots through the use of computer-based learning aids have the potential to reduce training time by 50-75 percent. In 1998, the first student pilots in the AGATE Unified Private-Instrument Pilot Training Curricula completed the training. Early results indicate significant reductions in total training time, total calendar time, and total cost for achieving an Instrument Flight Rules (IFR) rating.

The cumulative result of the AGATE Alliance during the 1994 to 1998 time period has produced a revolution in the research and technology deployment capacity for all sectors of the U.S. General Aviation industry. AGATE provided a voice for industry to provide national clarity and action on key technology development, certification, and standard-setting activities. During this time period, the general aviation industry research and technology capacity has advanced from virtually non-existent to world class in avionics, engines, airframes, and flight training.

(Bruce J. Holmes, b.j.holmes@larc.nasa.gov, 757-864-3863)

Optimization Using ADJIFOR-Generated Adjoint Code

The objective of the Airframe Systems Concept to Test (ASCOT) Project is to develop fast, accurate, and reliable analysis and design tools which significantly reduce development time and costs of aircraft designs. In support of the ASCOT objective, an automatic procedure for modifying existing complex aerodynamic codes for computation of design variable gradients has been developed. This results in code modifications being accomplished in 1 work week as opposed to approximately 1 year (figure 13).

Boeing Phantom Works applied this procedure to its aerodynamic optimization code, and it ran 20 times faster than the previous method (for a 500 design variable case). Future plans include extending this procedure from single discipline to multidisciplinary optimization methods for nonlinear problems.

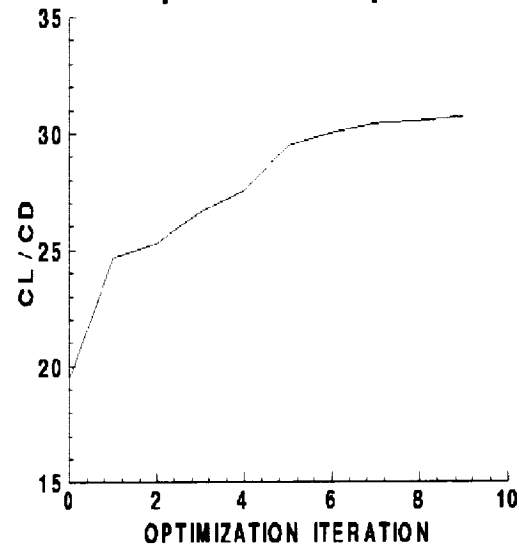
(Long Yip, l.p.yip@larc.nasa.gov, 757-864-3866)

Reducing Cost of Composite Airframe Manufacturing Through an Innovative Materials Qualification Process

Revitalizing the U.S. General Aviation (GA) industry is one of the 10 Enabling Technology Goals of NASA's Office of Aero-Space Technology. The General Aviation Element of the Advanced Subsonic Technology (AST) Program played a key role in accomplishing the GA revitalization goal.

One of the most significant accomplishments of the AST GA Element was the 1998 publication entitled Material Qualification Methodology for Epoxy-Based Prepreg Composite Material Systems. This publication documents the breakthrough process that allows airframe manufacturers to procure certified composite materials from vendors in the same manner that they have been able to procure metals for decades.

Improvement in CFD Optimization Speed



The capability to automatically generate an adjoint code for improving the aerodynamic optimization design cycle is shown.

Relative Run-Time

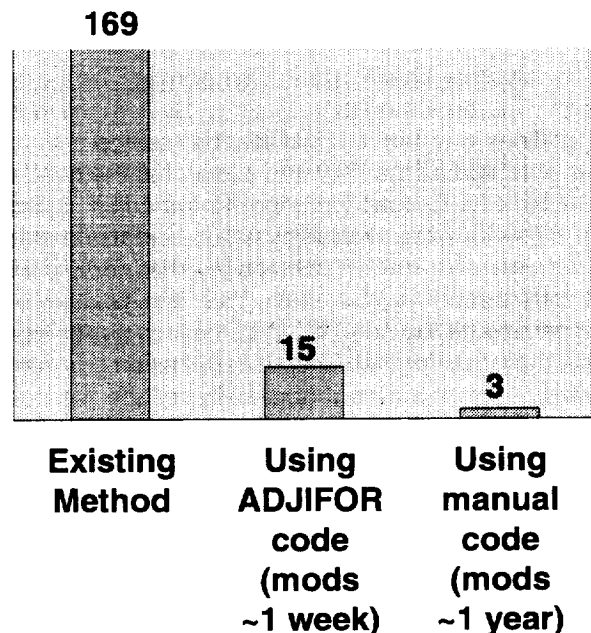


Figure 13. Optimization using ADJIFOR-Generated Adjoint Code.



Figure 14. Cirrus SR-20 Composite Fuselage.

In the decades since the introduction of synthetic composite materials for use in aerospace applications, the cost of materials qualification has inhibited expanded uses. Much of this cost has resulted from the extensive testing required by the FAA. Each airframe manufacturer intending to apply a composite material to a product has been required to submit detailed materials property reports to the FAA, regardless of whether they or other manufacturers had previously certified the same materials. Long ago, resulting from sustained statistical confidence in the ability of materials suppliers to meet common production standards, industry and FAA dispensed with such testing requirements for aluminum and other metals.

The Material Qualification Methodology for Epoxy-Based Prepreg Composite Material Systems publication outlines a materials qualification method that has been accepted by the FAA and eliminates the need for repeated tests to qualify composite materials. Specifically, it provides the method by which composite material vendors can market composites that comply with FAA certification requirements. This qualification process eliminates the need for airframers to qualify composite materials for their aircraft certification programs. Airframe manufacturers dramatically reduce the costs associated with using composite materials by buying materials that are already certified/approved by the FAA. As a result, the cost of FAA certification of new composite airframes is reduced by more than \$500,000 per material and the time required for certification of a new airplane is reduced by more than 2 years. These reductions in certification time and costs will make the use of composite materials a viable choice for small and large companies and will help generate the market forces necessary to foster the revitalization of the general aviation industry.

(Bruce J. Holmes, b.j.holmes@larc.nasa.gov, 757-864-3863)

First Generation Multipoint Wing Design Tools Calibrated

In fiscal year 1998, the Airframe Methods Element of the Advanced Subsonic Technology (AST) Program successfully met a major milestone with the calibration of the 1st generation multipoint wing design tools. The goal of the Airframe Methods Element is to reduce design cycle time by delivering integrated design methodologies and new aerodynamic concepts. These concepts and tools will enable revolutionary aircraft designs and faster design cycles while reducing aircraft operating costs, environmental impacts, and aircraft development risks. This element of the AST Program directly contributed to two of NASA's goals: reducing the cost of air travel, and providing next-generation design tools and experimental aircraft to increase design confidence, and cut the design cycle time for aircraft.

The design of a competitive commercial aircraft is influenced by many factors. Airline companies are interested in technologies that enable the mission to be successfully completed at the lowest cost. In incorporating new technologies, aircraft performance and control characteristics must be considered as well as manufacturing and operating costs. An integrated aircraft design considers all issues and optimizes the aircraft design for the range of conditions that the aircraft would expect to fly. This process is known as multipoint design.

The objective of the 1st generation multipoint wing design tools milestone was to develop a computer-based design capability which would serve to automate the wing design process and provide improved optimization capability over a range of flight conditions.

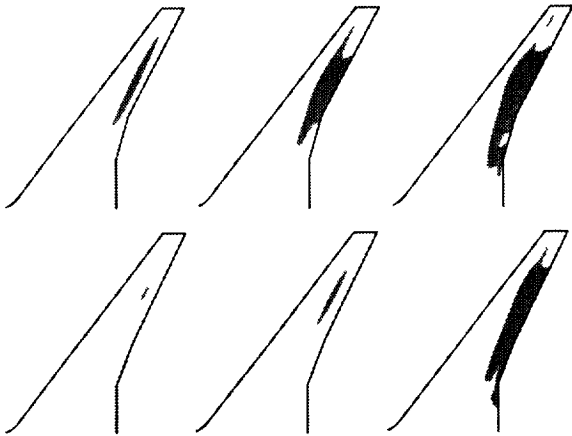


Figure 15. Multipoint Design Improves Performance by Delaying Flow Separation to a High Lift Coefficient.

The first step required the calibration of a number of potential multipoint analysis/design computer methods using existing data. This step enabled the aircraft developers to understand the capability of the different methods in predicting aircraft characteristics for different aircraft configurations and for different flight conditions. Based on the results of these calibrations, two computer design methods were selected for use in two projects, which would validate the methods. A 2-engine and a 4-engine existing aircraft configuration were redesigned using the selected multipoint design methods. Wind tunnel models were then built and tested to demonstrate that the computer design methods could correctly predict and optimize desired characteristics over a range of flight conditions. The designs included realistic constraints that aircraft developers face, such as structural, manufacturing, and performance considerations.

The advanced 2-engine and 4-engine multipoint wing designs were tested in NASA Langley's National Transonic Facility wind tunnel. The results from these tests agreed with the results predicted by the computer design methods, thereby validating the multipoint analysis/design methods selected. Figure 15 demonstrates the improvement in the flow field over a 2-engine wing that was realized utilizing the multipoint design tool. The shaded area in the figure identifies a region where the airflow over the wing has separated, or is not flowing smoothly over the wing. As the separated region over the wing increases in size, large losses in wing performance characteristics occur. The figure demonstrates how the multipoint design tool improves performance (lower half of figure) by delaying the formation of large areas of separation on the

wing until higher lift (C_L) was reached, as compared to the original configuration.

The successful completion of this milestone provides a means for aircraft designers to optimize the wing design over a range of flight conditions, which enables the overall performance of the aircraft to be improved. The ability to automate the wing design process provides a more streamlined and efficient approach and results in a decreased time to design a wing, all of which serve to reduce the cost of the aircraft design process and ultimately the cost of the aircraft.

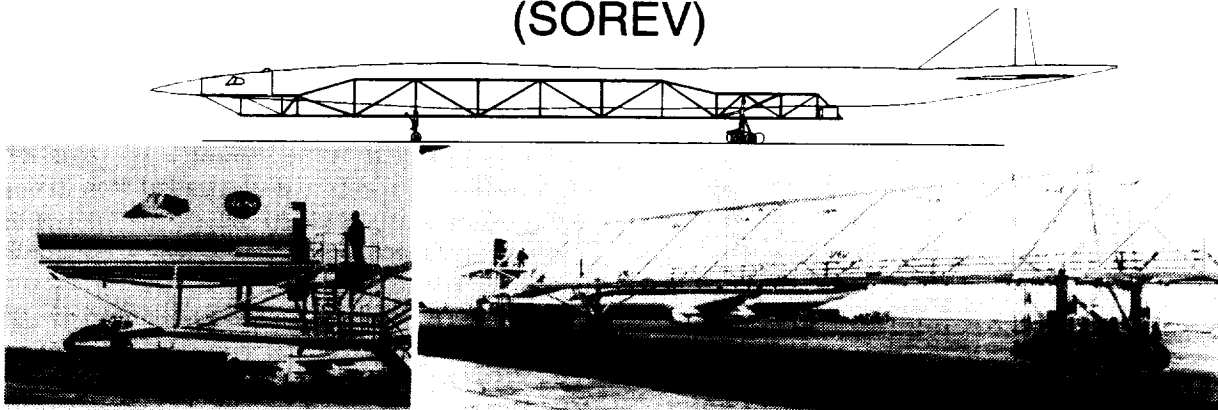
(Elizabeth B. Plentovich, e.b.plentovich@larc.nasa.gov, 757-864-1919)

Surface Operations Research/ Evaluation Vehicle

The High Speed Research (HSR) Program began to address the unique research issues associated with the taxi operations of High-Speed Civil Transports (HSCT). This has been made possible by the recent completion of the HSR Surface Operations Research/Evaluation Vehicle (SOREV), a full-scale HSCT ground testing vehicle. The vehicle (figure 16) is intended to emulate the landing gear footprint, turning performance, and flight deck geometry of the future supersonic transport. Some research issues originate in the unique aircraft geometry of a large HSCT where the pilots are located nearly 60 feet in front of the nose gear resulting in unusual turning behaviors. Many other issues arise because HSR-developed technologies will allow the replacement of the forward-facing HSCT cockpit windows with a sensor/display system to achieve weight savings and improved aerodynamic performance over the more conventional supersonic transport droop-nose configuration. While SOREV is a NASA Langley owned facility, it is being operated at Grant County Airport in Moses Lake, Washington, where HSR researchers from NASA Ames, NASA Langley, Boeing, and Honeywell were conducting surface operations testing. Moses Lake was picked as the sight to conduct the SOREV operations because of the variability of the weather, airport layout, and proximity to engineering support and airline access. Initial experiments are assessing the baseline geometry effects and evaluating front display integration issues with real side windows. Future experiments will determine sensor/display requirements, investigate HSCT requirements for supplemental taxi map displays based on Global Positioning System information, and resolve other key research issues.

(Daniel G. Baize, d.g.baize@larc.nasa.gov, 757-864-1071)

Full-Scale representation of HSCT Gear and Flight Deck placement
(SOREV)



Specifications

Weight: 90,000 lb
Length: 216 ft
Height: 24 ft
Speed: 23 kts

SOREV Studies

- Actual SOREV Operational Characteristics and Limitations
- Validation of Nominal XVS/ HSCT Surface Operations
- Evaluation of Display Field-of-View in Ground Operations
- Validation of Surface Operations Symbolology Set
- Safety and Meteorological Hazards in Ground Operations
- Validation of Multi-View Surface Operations Concept

Figure 16. The Surface Operations Research/Evaluation Vehicle.

High Speed Research Aeroelastic Handling Qualities

Aerodynamic research is providing potential concepts and validated analytical design and optimization methods for airplane configuration development and ride quality enhancement. These design methods will be used for drag reduction and for predicting aeroelastic stability and control characteristics which are necessary for the design of safe, controllable, and economically viable high-speed civil transport (HSCT) configurations.

In early 1996, the aeroelastic ground-handling problem for an HSCT was demonstrated in the NASA Langley Visual Motion Simulator (VMS) facility. Heave vibrations resulting from accelerating an HSCT across a benchmark rough runway were calculated. This heave vibration profile was synchronized with the ground roll of an existing HSCT airplane simulation model during a rejected take-off due to an engine failure. An extreme vibratory environment occurred at the pilot's station and was so severe that the pilot's ability to recognize the engine failure and the ability to maintain control were significantly impacted.

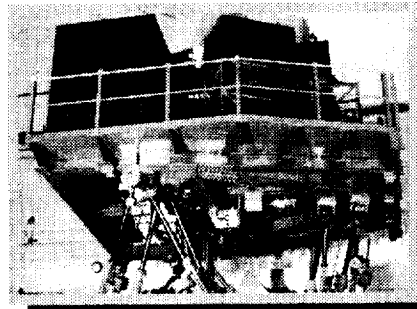
As a result of these investigations, industry and Langley are investigating the application of actively controlled landing gear for the HSCT to alleviate vibrations in the cockpit.

In January 1997, NASA and Unisys hosted a high-fidelity full-envelope simulation of an HSCT that included aeroelastic effects. The aeroelastic degrees-of-freedom were excited by both turbulence and pilot inputs and the resulting cockpit vibrations were realistically represented in the motion base. The accelerations for the aeroelastic model measured at the pilot station are in red in figure 17 while those for the rigid model are in blue. For an aggressive landing task, the Cooper-Harper flying qualities ratings were made significantly worse by the inclusion of these effects and in one case the test pilot repeatedly crashed.

In early fiscal year 1998, follow-on studies with an improved, parameterized version of the aeroelastic HSCT were conducted to determine design guidelines for actively suppressing structural vibrations. Desired levels of damping and feedforward cancellation (the ability to cancel the pilots' excitation of selected modes through the use of multiple control surfaces) were determined.

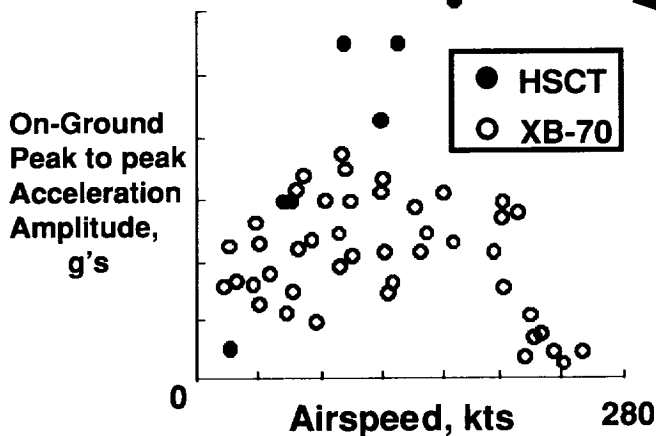
(Daniel G. Baize, d.g.baize@larc.nasa.gov, 757-864-1071)

HSR Aeroelastic Handling Qualities Established



On ground

In air



- New Simulation Technology
- Dynamic aeroelastic degrees-of-freedom incorporated in piloted simulation
- New flying qualities and control design criteria developed

— Aeroelastic Case
— "Rigid" Case

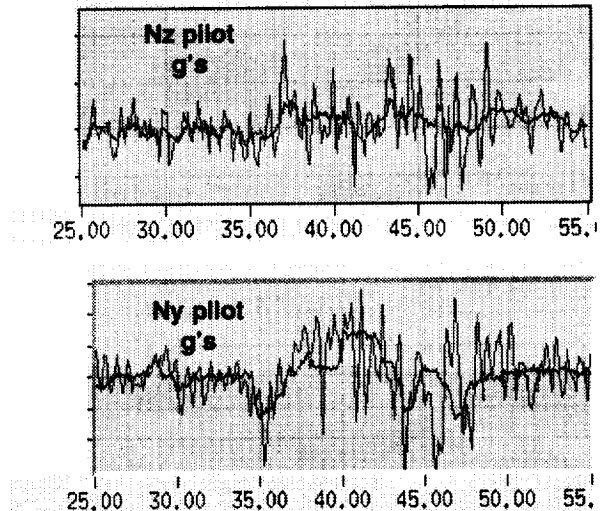


Figure 17. Simulation of High-Speed Civil Transport Aeroelastic Handling Qualities.

Testing Advanced Composite Materials for a Supersonic Transport

Future supersonic transports will fly at speeds greater than 1,500 miles per hour, at altitudes of 65,000 feet, and with surface temperatures of more than 300° Fahrenheit. Airplanes designed to operate at these temperatures using currently available metals would be too heavy. Researchers have developed a special new composite material to meet the temperature and durability requirements of the future transport. One of these is PETI-5 (Phenyl Ethynyl Terminated Imide), the fifth formulation developed in this family of resins. Composite materials made from graphite fibers and resins like PETI-5 are necessary to withstand the high temperatures, and to make the plane strong enough and light enough to be economically viable.

Wing and fuselage structures are being developed using high-temperature composite materials. Several



Figure 18. 40-inch-by-80-inch fuselage skin-stringer panel that was tested to 400,000 pounds.

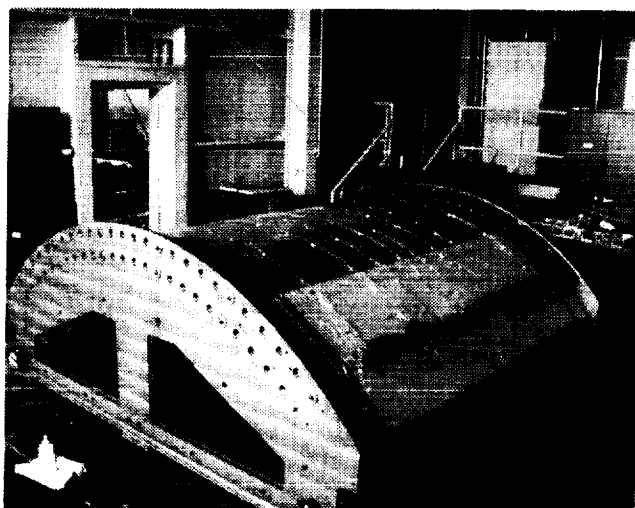


Figure 19. 6-foot-by-10-foot curved fuselage honeycomb sandwich panel that was tested to one million pounds in COLTS.



Figure 20. Single bay of a composite honeycomb sandwich main wing box that was tested at both room temperature and 300° F.

of the test articles that have recently been tested are shown in the figures. They were designed and fabricated by industry partners and were tested at NASA Langley Research Center.

One of these (figure 18) is a 40-inch-by-80-inch PETI-5 skin-stringer panel that was designed as part of the fuselage structure. This panel was subjected to more than 400,000 pounds of force before it cracked. Another PETI-5 fuselage panel (figure 19), a 6-foot-by-

10-foot curved honeycomb sandwich panel, was tested in the new Combined Loads Test System (COLTS) Facility at NASA Langley. It carried more than one million pounds of load before it failed. The third test article represents a single bay of the main wing box (figure 20). It is a composite honeycomb sandwich design that is 36 inches wide, 22 inches deep, and 64 inches long. It was tested at both room temperature and elevated temperature (300° F) conditions. All three of these test articles carried the required design ultimate loads before they failed.

Eventually, very large sections of a fuselage and wing will be designed, fabricated, and tested. Structural tests similar to these are necessary for FAA certification of airplane structures.

(Rodney H. Ricketts, r.h.ricketts@larc.nasa.gov, 757-864-1209)

Community Noise Trade Study Results

An environmentally acceptable, economically viable supersonic transport aircraft requires a series of acoustic trade studies to evaluate the benefits of alternative operational procedures for reducing community noise. While noise benefits can be achieved for most of these procedures, the options have to be assessed at a configuration level before they are shown to be effective strategies. The ultimate test is to balance the noise reduction achieved against any increase in vehicle weight or loss in overall performance. Some of these trade studies have been completed for the High Speed Research Preliminary Technology Configuration.

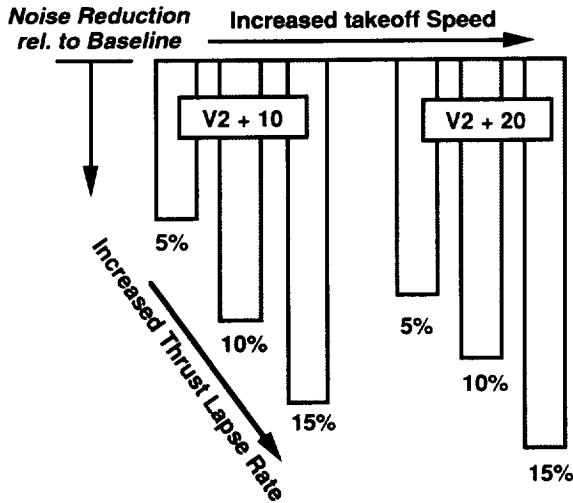
While there are demonstrated gains for the increased thrust lapse rate and increased takeoff speed as shown on the left side of the figure, there is an increase in takeoff noise associated with these sideline noise reductions. The final determination for the application of such a procedure awaits the further definition of the airplane and the certification standards, and the community noise requirements.

The certification procedure study result portrayed on the right side of figure 21 suggests a favorable benefit in reducing the noise at the noise monitoring station under the flight track of the airplane. The objective is to minimize the area between the noise profile and the "10 dB down" condition, as measured from the peak of the noise profile. The assumption is that the noise energy enclosed within this area will be the dominant influence on the measurement at the certification station. The delayed cutback option is shown to offer a noise-reduction benefit.

(Allen H. Whitehead, allen.h.whitehead@larc.nasa.gov, 757-864-7800)

Take-Off Operating Procedure Study

Objective: Reduce sideline noise through increased velocity and thrust lapse rate options.



Take-Off Certification Study

Objective: Reduce take-off noise under the flight path through alternative operational procedures

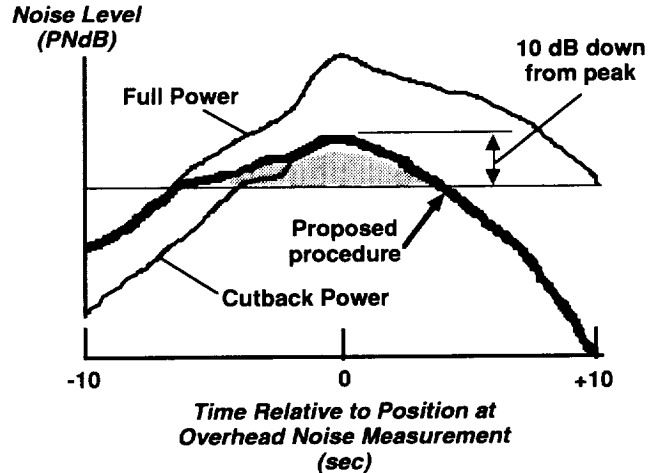


Figure 21. Trade studies generate trends and data for alternative strategies for meeting noise requirements.

Optimized Aeroelastic Concept

The Technology Integration element of the High Speed Research (HSR) Program merged the various disciplines into a complete vehicle system to measure the progress of technology development, evaluate options to support technology downselect decisions, and provide for the development of the baseline airplane known as the Technology Configuration. The Technology Configuration is maintained through trade studies that are conducted to continually refine the baseline concept and assess alternates as technology progresses in the HSR Program. Technology area progress is evaluated by integrating technology results and assessing the impact on vehicle viability.

A major challenge in the design of an aircraft such as the High Speed Civil Transport (HSCT) is the strong interactions which occur between disciplines such as aerodynamics, structures, and propulsion. If dealt with proactively, such interactions can be used to minimize the potential weight of a future HSCT; if ignored, such effects can cause excessive configuration weights. The HSR Program recognized the importance of these discipline interactions and developed an approach and methods for a simultaneous, multivariable optimization process to define sized aircraft configurations. The

objective of the HSR Optimized Aeroelastic Concept milestone was to demonstrate this approach by developing an optimized baseline configuration and using it to provide design recommendations for the Technology Configuration Airplane.

The Design Optimization Synthesis System (DOSS) has been developed (figure 22) to optimize wing thickness/twist distribution as well as planform and propulsion parameters to minimize the airplane take-off-gross-weight while satisfying the design mission specified for the HSR Program. The DOSS was exercised using the extensive technology data base already developed in the Program to generate sensitivity data and perform studies as a precursor to help define the December 98 Technology Configuration.

The optimized technology baseline airplane defined by the DOSS was the Optimized Aeroelastic Concept (OAC) specified in September 1998. Results from recent wing planform and engine cycle trade studies were used to define data response surfaces from which the OAC was selected using the DOSS tool. In addition to standard HSR linear design methods, the OAC study employed new higher-order data in the form of Navier-Stokes Computational Fluid Dynamics (CFD) solutions and comprehensive Finite Element

ACE is progressing towards significant Configuration Design Improvement

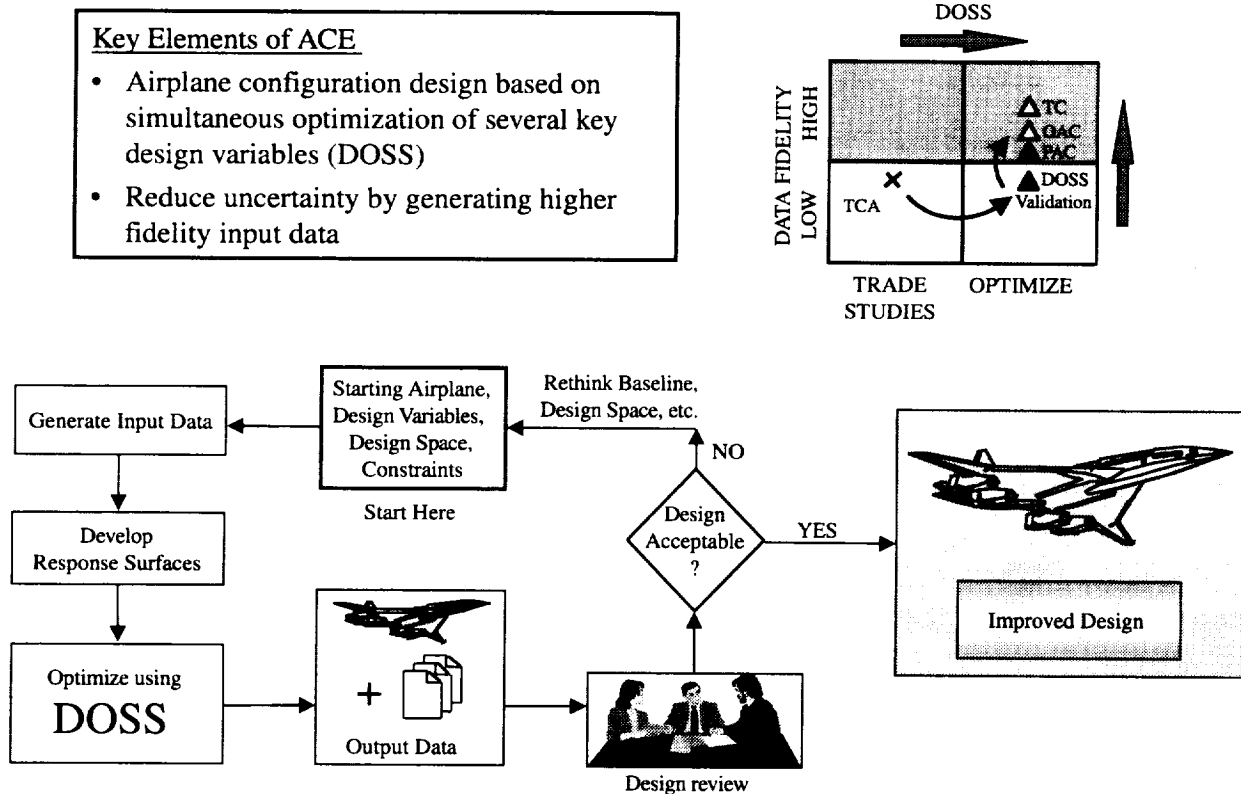


Figure 22. Configuration Optimization Process for Advanced Concept Engineering (ACE).

Method (FEM) analysis results to provide more accurate design variable sensitivities. Three planform and three engine cycle variables were optimized. Parametric weights methods were used to model five wing thickness permutation variables. A new horizontal tail-sizing method based on empirical tail-sizing and balancing data was implemented for the first time. Using a new approximate method for predicting wing spanwise end-load values, the DOSS was able to optimize the configuration while preventing the end-load values from violating the HSR design goals. The resulting optimized configuration offered a reduction in takeoff gross weight of nearly 10 percent, a level comparable to the vehicle design payload weight.

(William P. Gilbert, w.p.gilbert@larc.nasa.gov, 757-864-6392)

Cryogenic Pressure Sensitive Paint

Global surface pressure measurements, using pressure sensitive paints, offer the aerodynamic researcher a unique way to view the model pressure distribution that is not possible with conventional pressure taps. Instead of discrete point measurements,

pressure sensitive paints provide pressure data for the entire model surface. Significant savings of time and money can be obtained when using pressure sensitive paints in lieu of pressure taps. Model fabrication and preparation time is reduced since no or very few pressure taps are needed. The test cycle time is shortened resulting in quicker turn-around of the data.

The pressure sensitive paint fluoresces when illuminated with ultraviolet light. The intensity of this fluorescence is inversely proportional to the level of oxygen partial pressure on the painted surface. This phenomenon is known as oxygen quenching. When applied to a wind tunnel model it is possible to determine the pressure anywhere on the surface. In cryogenic wind tunnels such as the National Transonic Facility, pressure sensitive paint testing has not been available since the tunnel is purged of any oxygen at the cryogenic test conditions. A low-temperature pressure sensitive paint was developed that requires only small traces of oxygen in order to be quenched. By injecting small amounts of air into the flow the paint can be quenched by the oxygen. The requirements on the paint were that it be able to be applied by conventional techniques, have low temperature sensitivity, have

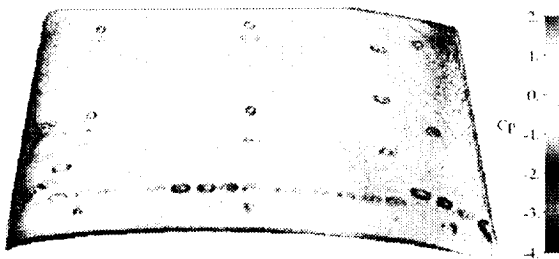


Figure 23. Pressure sensitive paint data image from 0.3 Meter Cryogenic Transonic Tunnel test, $M=0.70$, $\alpha=2^\circ$, $T=-250^\circ\text{F}$ (flow is from left to right). (Color version is on report website.)

good adhesion for high Mach number conditions, and require no model surface modifications.

Tests to evaluate the low-temperature pressure sensitive paint were conducted in the Langley 0.3 Meter Cryogenic Transonic Tunnel on a two-dimensional airfoil model. The test conditions included Mach numbers of 0.5 and 0.7 over the temperature range from -250°F to 30°F . The paint was developed for universal application to metal and other model materials without any special preparation or surface modifications. Since the paint fluorescence is quenched by the presence of oxygen, it was necessary to inject air into the nitrogen-cooled tunnel in order for the paint to respond. Oxygen concentrations of 2000 parts per million were determined to be the optimal for the test conditions studied. The paint proved to have a low sensitivity to temperature. An example of the results obtained is shown in figure 23. Test conditions for this image were $Mach=0.7$, $\alpha=2^\circ$, and $T=-250^\circ\text{F}$. The flow is from left to right. The large color change at around 60% chord shows the pressure change across the shock on the model. This successful application of a pressure sensitive paint under cryogenic and non-cryogenic test conditions is a first in the world using conventional application procedures and standard models. A patent application has been filed.

(Clifford J. Obara, c.j.obara@larc.nasa.gov, 757-864-3941)

Control Surface Deflection Measurements in Near Real-Time

The non-contact, near real-time measurement of remotely actuated control surface deflection angles of wind tunnel models is especially critical during testing of new wings employing smart materials. Smart materials offer the promise of increased lift, reduced drag,

and improved pitching and rolling moments through hingeless and smooth contoured trailing edge control surfaces. Recently wing twist, flap, and aileron deflection angles were measured for both the conventional and smart configurations during a DARPA/Northrop Grumman Smart Wing test (figure 24) at the Langley Transonic Dynamics Tunnel with an enhanced video model deformation system that utilizes single camera, single view photogrammetry. This was the first known wind tunnel application in which control surface and twist measurements were made optically in near real-time. The near real-time display of the enhanced video deformation system was used to adjust aileron deflection angles (controlled by shape memory alloys) and twist (controlled by a torque tube) during flow. The video deformation system was also used to record time histories in order to measure aileron response time. Pixel clock synchronization of the frame grabber was employed to further improve data reliability and repeatability. Based on wind-off calibration tests the wing twist and flap/aileron deflection angle uncertainties were 0.03 and 0.25 deg respectively. The deformation data will be used to assess performance enhancements due to the use of smart materials.

(A. W. Burner, a.w.burner@larc.nasa.gov, 757-864-4635)

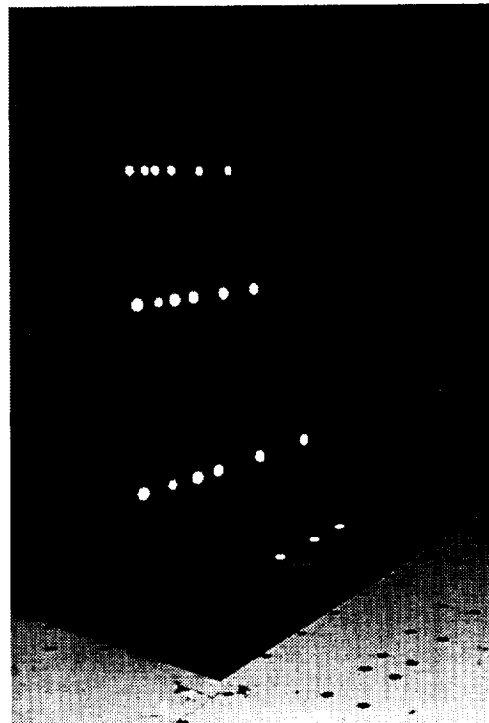


Figure 24. Smart wing as tested at the Transonic Dynamics Tunnel with retroreflective dots used for deflection measurements.

Thermal Imaging in Hypersonic Flowfields

Infrared imaging is a non intrusive, diagnostic technique which is capable of making quantitative, global temperature measurements. In this series of tests, a commercially available infrared thermography system was used to globally determine the time-temperature history of a target subjected to a hypersonic flow. This study was conducted in Langley's 8-ft High Temperature Tunnel using several models including a BF Goodrich Aerostructures Group thermal protection system (TPS) metallic tile and thermal blanket models, and a Hughes/Standard Missile forebody model in a Mach 7 flow.

The imaging system used in this experiment detected infrared radiation in the 8 to 12 micron region of the spectrum and generated real time video data at 30 frames per second. The scanner was located in the facility's test section, and above the model, within a pressurized chamber. Optical access was gained through a single anti-reflection coated Zinc Sulfide window and a gold coated mirror above the test article. During testing, the imaging system provided a video signal of the temperature gradients induced on the surface of the model as seen in figure 25. These temperature gradients resulted from the models' interaction with the high speed flow.

Real time infrared video data depicting the global time-temperature history of the model was generated during testing. Once the radiometric properties of the model are established, this minimally intrusive temperature measurement technique gives researchers large amounts of quantitative information without the complexity of managing large numbers of discrete temperature sensors. Use of this technique can greatly reduce the time required for model fabrication and installation into the facility due to the reduced number of sensors needed for testing.

(Stephen E. Borg, s.e.borg@larc.nasa.gov, 757-864-4747)

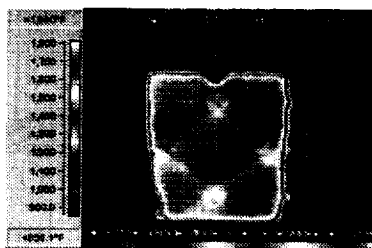


Figure 25. Infrared thermographic data showing temperature distribution on the model surface subjected to hypersonic conditions. (Color version is on report website.)

TU-144 Structural/Cabin Noise Experiment Instrumentation

Instrumentation was developed to fly on the Russian Tupolev 144LL supersonic flying laboratory for a Structural/Cabin Noise Experiment. This experiment is part of the TU-144 Airworthiness Flight Test activity conducted under NASA's High Speed Research (HSR) Program. An overall HSR program goal is to learn as much as possible from the existing aircraft before undertaking development of a full scale US vehicle. The Structure/Cabin Noise Experiment's goal is to characterize the exterior and interior noise environments, leading to quieter conditions for future passengers. In particular, the data will be used to improve a turbulent boundary layer pressure fluctuation model, improve a near field jet noise source model, develop an inlet noise source model, and validate a turbulent boundary layer/structure interaction model. The Tu-144 project is managed and coordinated by the Dryden Flight Research Center in cooperation with the Boeing Commercial Airplane Group.

The instrumentation and data acquisition system consists of pressure transducers for boundary layer noise measurements for flush and non-flush conditions, accelerometers for fuselage structural dynamic response data, microphones for cabin noise data, flow direction measurements using flow cones on three separate windows recorded by three video cameras. The core data acquisition system is capable of amplifying low level analog signals and recording 32 analog data channels sampled at a rate of 40KHz. The system is installed in a separate equipment pallet and receives only power from the research aircraft. Data is recorded on magnetic tape in digital form for post flight processing. Because of additional instrumentation utilized in a second phase of tests, a Remote Analog Multiplexer unit was developed. The new unit quadrupled the channel capability of the system with a minimum of on-site modifications to the instrumentation system previously installed in the Tu-144 aircraft. Two additional 18 Channel Analog Signal Amplifiers were also integrated into the system, for a total of 5 amplifiers. An earlier version of the data system has successfully flown on the Tu-144 aircraft during the fall of 1997 and winter of 1998 at Zhukovsky, Russia. Test data were measured on a total of 16 supersonic and subsonic points in addition to take-off, landing and ground engine run-ups. The enhanced system was scheduled for research flight support during the winter of 1998 and 1999 and will include a number of subsonic and supersonic measurements to Mach 2.0.

(Thomas A. Shull, t.a.shull@larc.nasa.gov, 757-864-1837)

A MicroElectroMechanical Systems (MEMS) Attitude Sensor

A model attitude measuring system has been developed with a MEMS accelerometer. The advantage of the MEMS accelerometer is its low cost, ease of use, ruggedness, and small footprint. This attitude sensor system measures 0.45 in x 1 in x 0.15 inch in size, weighs about six grams, and costs less than 10% of the standard angle-of-attack measurement system. It is an ideal and disposable tilt sensor capable of making model deformation measurements of the test articles as well as attitude measurements of the support structures of wind tunnels. It will complement the standard attitude sensor system currently in use where the standard system cannot be used. The system developed is also an excellent candidate to replace the piezoelectric accelerometer used in vibration measurements.

Its static performance has been found to meet the accuracy requirements of model attitude measurements of 0.1 degree. One such 25-g unit demonstrated a 0.0574 degree calibration uncertainty error at 95% confidence level. Sine wave rectification error is less than 0.1 degree per g from 20 to 1000 Hz, sensitivity is 0.158 volt per g, and linearity is rated at 0.113% of the span. Two units were used to make attitude measurements on the Smart Wing test at Langley's Transonic Dynamic Tunnel. Figure 26 shows the sensor package and photomicrograph of the MEMS accelerometer and interfacing circuit.

(Ping Tcheng, p.tcheng@larc.nasa.gov, 757-864-4717)

A MicroElectroMechanical Systems (MEMS) Thermal Shear Stress Sensor Array

A MEMS Thermal Shear Stress Sensor Array has been tested in the 20-Inch by 28-Inch Shear Flow Tunnel (20x28 SFT). Measurement of shear stress values at the surface of an airfoil is important for both wind tunnel testing and active flow controls over the airfoil. The sensor array tested is a rigid substrate type and suitable for applications on flat surfaces. The sensor array consists of three span wise rows of 25 sensors each sharing an electrical connection on one side; a total of 75 sensors constitute an array. The important aspect of these sensor arrays is that they exhibit improved sensor characteristics over the standard surface mounted hot films in several areas: low substrate heat conduction, dense packaging, low electrical current requirements, and small size. The sensing element is 2 microns x 3 microns, which is diffused on a 200 microns x 200 microns vacuum insulated silicon substrate.

The tunnel tests were conducted on a full span splitter plate 145 inches downstream of the leading edge of the splitter plate. The flow on the plate and the walls was tripped by a 2" sandpaper strip located 8" downstream of the elliptical leading edge of the splitter plate to fix the transition location in the tunnel. The tests of this sensor array were conducted under a nominally zero pressure gradient flat plate turbulent boundary layer. Mean flow measurements were taken with a flattened Pitot tube to determine the shear at

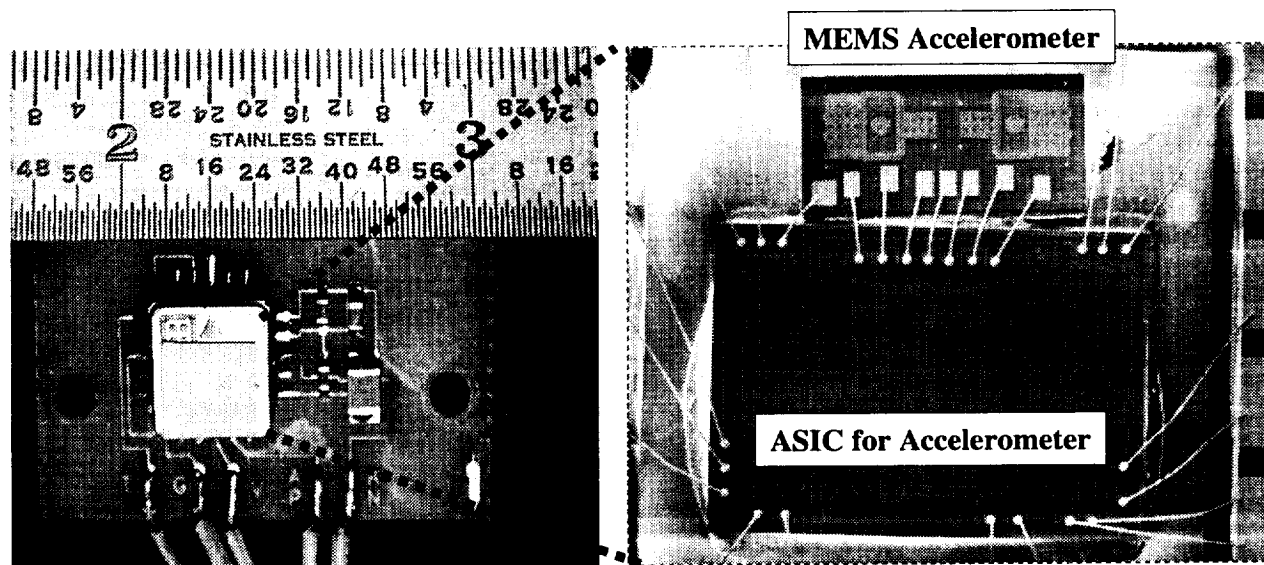


Figure 26. Attitude Sensor System Package and MEMS Accelerometer with Application Specific Integrated Circuit (ASIC).

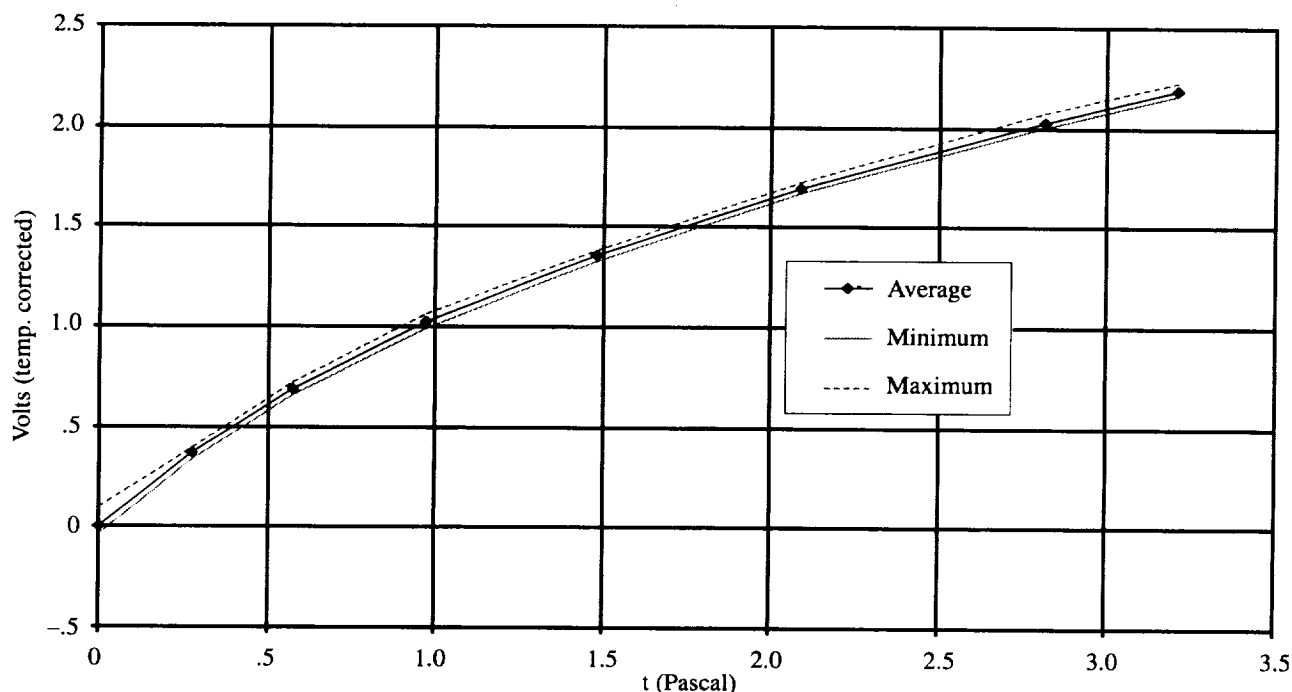


Figure 27. MEMS Thermal Shear Stress Sensor Calibration.

each test velocity. Skin friction was determined by using the acquired data from the Pitot tube as a flattened Preston tube. Shear stress values from 0.25 Pascals to 3 Pascals have shown the sensors to be repeatable within 3% for shear stress values greater than 1 Pascal and 9% for the lowest shear values measured. The measurement of shear stress with this type of sensor is sensitive to changes in temperature in the immediate vicinity of the sensors so one sensor was connected to a bridge circuit to measure local changes in temperature. For this series of tests, the front row of sensors was used to measure shear stress and a sensor from the second row was used for measuring local temperature variations. A series of tests was conducted to determine the repeatability of shear stress measurements and evaluate the effectiveness of using a local temperature measurement for temperature compensation of the sensor.

The test results for a typical sensor are shown in figure 27. This plot summarizes all data taken with these sensors over a period of 3 days and shows a high degree of repeatability. Future work includes a use of a shear stress sensor array on a flexible substrate for the highly curved surface of an airfoil as well as applications of an integrated sensor cluster on a flexible polyimide substrate for measurements of shear stress, pressure, and temperature within a small area.

(Michael A. Scott, michael.a.scott@larc.nasa.gov, 757-864-4666)

A MicroElectroMechanical Systems (MEMS) Digital Pressure Sensor System

A digital pressure sensor system has been developed which consists of a capacitive type MEMS pressure sensor integrated with an on-chip signal processing integrated circuit. Applications of the digital pressure sensor system are for measurements of pressure on an airfoil in wind tunnels or in flight. The important aspect of this system is that it exhibits the performance of a piezoresistive pressure sensor and has the additional capability of delivering digital output signals from the in-model on-board sensor and health status of the sensor. Such measurement capabilities are important for making reliable and cost-effective pressure measurements. The system consists of (1) an integrated capacitive MEMS pressure sensor with a co-located interfacing electronic circuit, (2) a Programmable Logic Device (PLD), (3) an external clock, and (4) a host computer/processor. The PLD and the host processor can accommodate a number of pressure sensors and provide data processing. The integrated capacitive pressure sensor is capable of providing 15 data bit digital output using a serial peripheral interface, and also running diagnostic modes for checking the basic performance of the electronics chip and the sensor. The sampling rate of the sensor can be as high as 78 kHz per second.

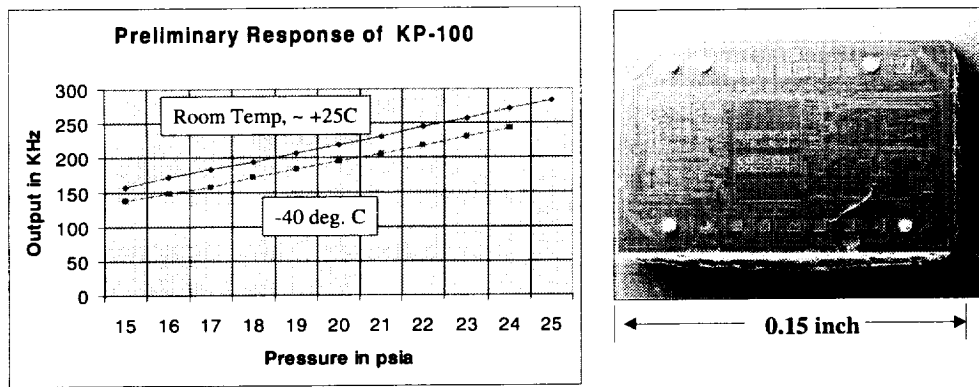


Figure 28. Pressure Responses of a Typical MEMS Capacitive Integrated Digital Pressure Sensor System (left). MEMS Digital Pressure Sensor with Interfacing Analog and Digital Circuits (right).

Test results of a typical digital pressure sensor system at two different temperatures and a photomicrograph of the integrated pressure sensor are shown in figure 28. These sensors (called KP-100) exhibited a nearly linear response to pressure changes at both temperatures tested. Further characterization of these sensors is under way for determining the temperature dependency of sensitivity and linearity. Future work includes the development of a high speed multichannel embedded integrated digital pressure sensor system with wireless data transfer capability that is software configurable from the host processor.

(Seun K. Kahng, s.k.kahng@larc.nasa.gov, 757-864-7553)

A Radio Frequency Digital Data Transfer System for Wind Tunnel Applications

Wireless data transfer of aerodynamic data from a wind tunnel test model to the test facility control room and the office of the researcher are desirable when a wind tunnel test is performed. A radio frequency "hopping" spread spectrum telemetry system with access from the control room and any local area network has been developed. Applications of such a telemetry system and in-model signal conditioner will enhance signal-to-noise ratio and eliminate problems associated with data transfer cables that extend for hundreds of feet. Furthermore, the telemetry system will reduce the time required for test model installation and removal, which in turn reduces wind tunnel operational cycle time and costs.

The telemetry system consists of an in-model and an out-of-tunnel unit. The in-model unit consists of (1) digital data transfer electronics, (2) a Radio Frequency (RF) transceiver, (3) a communication controls processor and (4) an antenna. The out-of-tunnel unit consists of the same components as the in-model unit

and an EtherNet card for the local area network system.

The telemetry system has been tested wind-off in the Langley 16 Foot Transonic Tunnel, and the results of the test show that data transfer rate of 212,000 bits-per-second has been achieved. With a properly selected location for the out-of-tunnel unit antenna, a satisfactory signal strength level has been established for a reliable data transfer. The frequency of the telemetry system is 2.4GHz, and operational protocol is compliant to the industry standard WLIF (Wireless LAN Interoperability Forum).

A picture of the telemetry system used in the tunnel test is shown in figure 29. Near term future work includes the development of a PC-104 based telemetry system with an improved data transfer rate and reduction of overall physical dimensions for the in-model unit.

(Seun K. Kahng, s.k.kahng@larc.nasa.gov, 757-864-7553)

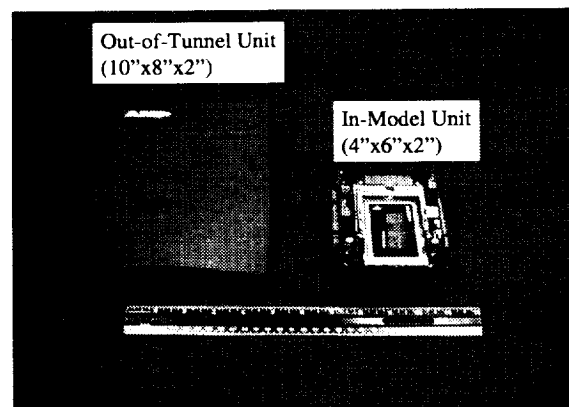


Figure 29. Telemetry System Tested in the 16-Foot Transonic Tunnel.

Cryogenic Electronically Scanned Pressure (ESP) Module

Conventional ESP modules have served the aerospace industry well for 25 years. Their operation in a cryogenic environment, however, introduces several problems that must be addressed. For protection against the cold temperatures they must be installed in a heater box, which takes up space and makes difficult their installation into a model. The need for periodic on-line calibration during a test requires a built-in sliding valve to apply calibration pressures, which not only requires test interruptions for calibration but is a leading cause of hardware failure. Finally, the pneumatic tubes needed to service the sliding valve and the large copper cable needed to supply power to the heater box create a shunt across the force balance, bridges the metric and non-metric parts of the model-sting assembly, and leads to an error in the force balance measurement. For this reason, force balance measurements and surface pressure measurements must be performed in separate test runs.

The cryogenic ESP module incorporates materials, processes, and electronics that are amenable to operation directly in the cryogenic environment. A temperature sensor on each silicon pressure die permits elimination of the sliding valve for calibration, for each pressure die is calibrated versus temperature and reference pressure in a cryogenic pressure calibration laboratory and need not be recalibrated for several months. The calibration window includes temperatures from +50 to -160 degrees over the full range of the pressure die. Figure 30 shows the total uncertainty (nonrepeatability, hysteresis, and nonlinearity) versus temperature for a 16-channel prototype module at a reference pressure of 1 atm. A total uncertainty not

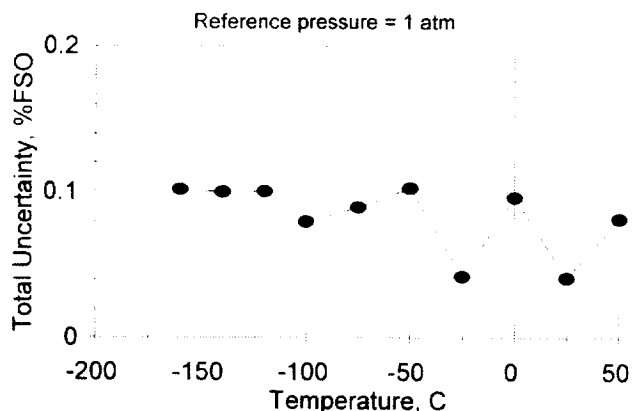


Figure 30. Total uncertainty in percent of full scale output versus temperature at a reference pressure of 1 atm.

exceeding 0.1% of full scale output was achieved over the full temperature range. The module will meet the specifications of noncryogenic applications as well. A 64-channel cryogenic module, currently being fabricated, is expected to be ready for a test in the National Transonic Facility at the end of 1999.

(Allan J. Zuckerwar, a.j.zuckerwar@larc.nasa.gov, 757-864-4658)

Electronically Scanned Pressure (ESP) Module Verification System

The ESP (Electronically Scanned Pressure) Module Verification System improves wind tunnel operational efficiency through increased ESP system reliability. Failures that result in wind tunnel test interruptions, loss of data, downtime, and post-test data corrections will be reduced. The ESP Module Verification System consists of a Pressure Systems, Inc. System 8400, which was modified and automated to verify the functions of the System 8400 Module before installation. These checks include tests of the shift block, pressure sensors, electronics, and tests for internal leakage.

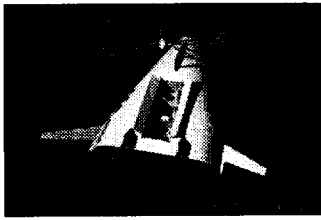
The repair records of Langley-owned ESP systems show 35 unscheduled tunnel downtimes as a result of ESP failures. Detecting leaks and channel cross talk prior to installation should decrease these unscheduled downtime by 25% for a cost savings of \$500,000 per year. Also, it will decrease module replacement during model preparation and testing. This should reduce model buildup time and test day tunnel preparation resulting in a long-term workforce decrease of 5%. In addition, the improved performance of the ESP modules will increase data quality and reduce the need of post-test data corrections.

An ESP Module Verification System has recently been put into operation at the 14 X 22 Foot Subsonic Tunnel at Langley Research Center.

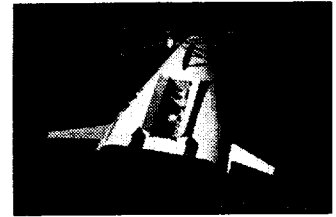
(Willard Bauserman, w.bauserman@larc.nasa.gov, 757-864-4737)



Figure 31. An ESP module is prepared for a verification demonstration.



Pillar Three: Access to Space



Low-cost space access is the key to unleashing the commercial potential of space and greatly expanding space research and exploration. Through integration of aeronautical principles with commercial launch vehicles, a ten-fold reduction in the cost of placing payloads in low-Earth orbit is anticipated within the next decade. An additional ten-fold cost reduction in the decade beyond is the far-term goal for low-cost space access.

Hyper-X

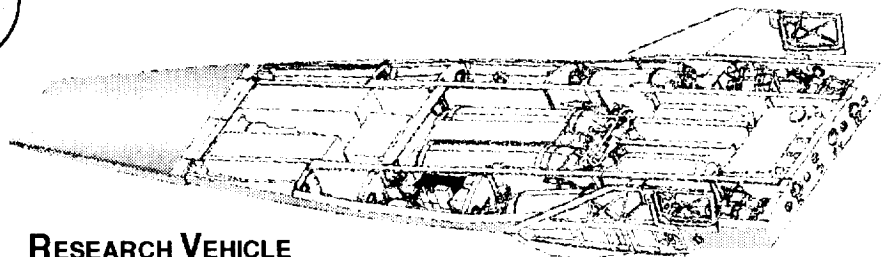
As a step toward opening the frontiers of atmospheric flight and reducing the cost of access to space, NASA has embarked on the Hyper-X program (figure 32). This program will, for the first time ever, fly air-breathing scramjet-powered X-43 Hyper-X Research Vehicles (HXRV) at speeds up to 10 times the speed of sound (Mach 10). The first flight, at Mach 7, is planned for early in the year 2000. NASA Langley

has the lead for the program and is responsible for Hyper-X technology development. NASA Dryden Flight Research Center manages the Hyper-X flight project.

In early 1998, the X-43 critical design review and a major series of X-43 research vehicle-to-booster stage separation wind tunnel tests were successfully completed. The first Mach 5 engine ground tests were conducted in mid-1998. In August, the Hyper-X Engine

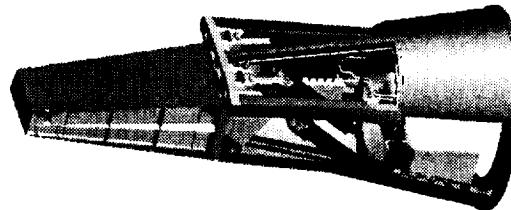


HYPER-X HARDWARE—UNDER CONSTRUCTION

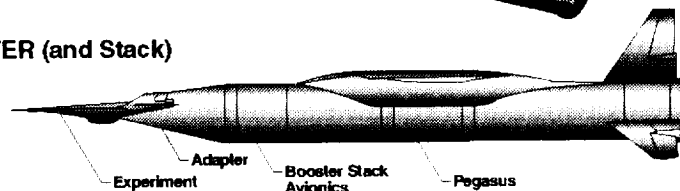


RESEARCH VEHICLE

ADAPTER



BOOSTER (and Stack)



Experiment Adapter Booster Stack Avionics Pegasus

Figure 32. Vehicle, adapter, and booster stack pictures.

Model (HXEM), the High-Speed Scramjet Model (HSM), and the first Mach 7 flight engine (HXFE) were delivered to NASA. The HXEM and HXFE were to be tested in the Langley 8-Foot High Temperature Tunnel and the HSM in the HyPulse Facility in 1999. In November 1998, the first X-43 airframe was delivered to the Micro Craft Tullahoma, TN, facility for systems integration. This vehicle was to be delivered to Dryden in 1999, followed by the booster, and Hyper-X Launch Vehicle (HXRV) in late 1999, in preparation for the first Mach 7 flight in early 2000.

To expedite the first flight and minimize overall program risk and cost, significant government participation and deliverables are included as a part of the program. The NASA Langley and Dryden team continue to supply deliverables on time. NASA Langley contributions in 1998 include the detailed analysis of the Mach 7 airframe and scramjet (supersonic combustion ramjet) engine structure and performance, computational analyses of the stage separation, wind tunnel testing, and design of the Mach 10 vehicle. A large number of wind tunnel tests of fifteen models have been conducted at Langley in support of aerodynamic and propulsion design and database development. NASA Langley continues to provide extensive computational fluid dynamics support and is currently working to solve challenging Hyper-X wing and tail leading edge design issues for the Mach 10 vehicle.

(Charles R. McClinton, c.r.mcclinton@larc.nasa.gov, 757-864-6253)

Space Transportation Technology

Langley plays a critical role in the Agency's program of space transportation technology development. This program seeks to foster truly low-cost, affordable access to the space environment, by advancing those technologies that will enable deployment of future space transportation systems to provide "routine" access to low-Earth orbit at a fraction of the cost of today's space shuttle and expendable launch vehicle fleets. The program's objective is embodied in the "Access to Space" enabling technology goal to *"reduce the payload cost to low-Earth orbit by an order of magnitude, from \$10,000 to \$1,000 per pound, within ten years."*

The space transportation technology program approach includes the design, build, and flight test of advanced technology demonstration vehicles, as well as a robust program of technology development and hardware testing in ground-based facilities. The demonstrator vehicle components of the program today include the X-33 and X-34 flight test vehicles being developed through NASA partnerships with the Lock-



Figure 33. X-33 Aerodynamic Loads Model in Unitary Plan Wind Tunnel.

heed Martin Skunk Works and Orbital Sciences Corporation, respectively. Langley has played significant roles in support of the industry partners in both of these programs, and is a leader in the advanced structures and materials development efforts within the ground-based technology element of the program.

X-33—Langley responsibilities within the X-33 program include: wind tunnel testing to determine the aerodynamic characteristics of the vehicle over its entire flight test envelope, definition of the aerodynamic heating characteristics of the vehicle in high-speed flight, pre-flight qualification testing of the vehicle's metallic thermal protection system, development and testing of advanced cryogenic insulation systems for the vehicle's fuel tanks, and development and implementation of advanced sensor systems to monitor the operational "health" of those tanks.

During 1998, extensive aerodynamic testing of the X-33 configuration was performed, in six different wind tunnels, to provide data required for the design of the vehicle's structure, thermal protection and flight control systems, and to enable planning for its flight test program. Tests in the 14 x 22-Foot Subsonic Tunnel provided data for definition of the vehicle's low-speed aerodynamic characteristics, including the effects of ground proximity, applicable to the approach and landing phase of flight. Testing performed in the 16-Foot Transonic and Unitary Plan Wind Tunnels provided data on the dynamic stability characteristics of the X-33 at transonic and supersonic flight conditions. Aerodynamic force and moment testing conducted in the 20-Inch Mach 6 (figure 34) and 31-Inch Mach 10 facilities provided definition of X-33 aerodynamic performance at hypersonic (more than 5 times the speed of sound) flight conditions. Wind tunnel testing was

complemented with extensive computational fluid dynamic (CFD) analyses that were used for validation of the experimental results, and to enable accurate definition of aerodynamic characteristics for flight conditions at which wind tunnels could not provide adequate simulation. Another series of tests in the 16-Foot Transonic and Unitary Plan Wind Tunnel facilities provided aerodynamic loads information to support the design of the vehicle's load-carrying structure and the actuators which will move its aerodynamic control surfaces in flight.

At the highest altitudes planned for X-33 flight tests (above 250,000 feet), the air is too thin for the vehicle's aerodynamic control surfaces to be effective in controlling its flight. At these altitudes, a reaction control system, comprised of small rocket engines or jets, located on the aft end of the vehicle will be used to provide attitude control. As the vehicle descends to lower altitudes, where the aerodynamic control surfaces become effective, there is a region of flight where both the jets and the aerodynamic control surfaces will be used. In this flight regime, the gas plumes that exhaust from the firing jets interact with the aerodynamic flow around the vehicle. These interactions both influence the effectiveness of the jets, and alter the aerodynamic characteristics of the vehicle when the jets are firing. In order to provide the required understanding of these interactions, highly specialized wind tunnel testing was

performed in both the Unitary Plan Wind Tunnel (at supersonic speeds) and the 31-Inch Mach 10 Tunnel. These tests provided reaction control jet / aerodynamic interaction data that is being used in design of the X-33 flight control logic for this phase of flight.

Another area of significant importance to the design of the X-33 is definition of the aerodynamic heating environment the vehicle must withstand at hypersonic speeds, information which is critical for design of the vehicle's thermal protection system (TPS). Langley work in this area has specifically focused upon understanding and prediction of the phenomenon of "transition" of the airflow over the vehicle's surface from a laminar to a turbulent state. At a given flight condition, if that flow is turbulent, the resulting transfer of heat (due to friction) into the vehicle's TPS can be as much as two-to-four times what it would be if the flow state were laminar. Consequently, the ability to accurately predict the occurrence of this "boundary layer transition" is critical to enable effective design of the vehicle's TPS, and to properly plan and tailor its flight test trajectory profiles. Extensive wind tunnel tests and complementary computational fluid dynamic (CFD) modeling were performed in order to understand and predict this phenomenon for the X-33 flight test vehicle. Wind tunnel tests provided experimental evidence of the occurrence of boundary layer transition at a variety of flow conditions and vehicle attitudes, and the CFD analyses provided mathematical definitions of the local flow conditions where the phenomena occurs. The experimental test program included investigation of the effects of "pillowing" of the metallic thermal protection panels (thermal expansion at high temperature that will cause them to deform in flight, to a shape much like a pillow) on the transition phenomenon. The result of these complementary analyses is establishment of criteria and methodologies to predict the occurrence of boundary layer transition for the X-33 in flight. Methods developed are currently being used in thermal protection system design, and development of X-33 flight test trajectories.

Flight environmental testing of the X-33's windward surface metallic thermal protection system was also performed in 1998. This testing, conducted in the 8-Foot High Temperature Tunnel (figure 35), subjected a full-scale array of seven X-33 metallic TPS panels to an aeroconvective environment simulating the aerodynamic pressure and TPS surface temperature levels expected in flight. The panel array was tested in the nominal installation configuration, and in configurations which simulated panel-to-panel mismatches, missing fasteners, and various types of panel damage. Additional testing was also performed in this facility on the leeward thermal protection configuration, which is

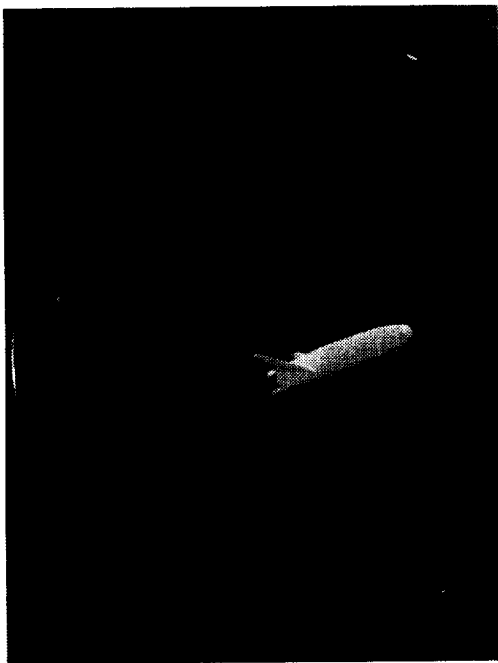


Figure 34. X-33 Ceramic Heat Transfer Model in 20-Inch Mach 6 Wind Tunnel.

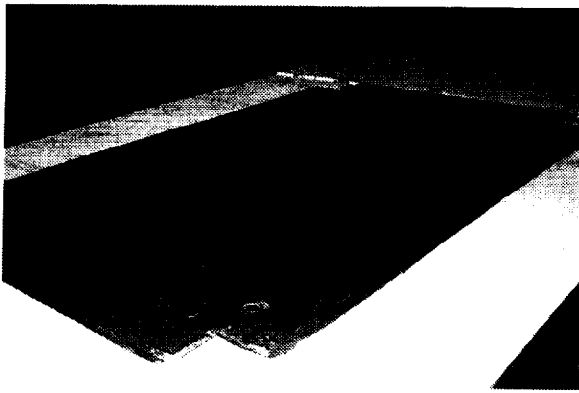


Figure 35. X-33 Metallic Thermal Protection System Panel Array in 8-Foot High Temperature Tunnel.

comprised of flexible blanket TPS material bonded to a composite skin substructure. Successful completion of these tests was critical to "flight qualification" of the X-33 thermal protection system.

Evaluations of multiple options for insulation of the X-33's aluminum lithium oxygen tank and graphite-epoxy hydrogen tank were performed in the Thermal Structures Laboratory. These tests subjected 1x2-Foot panels of candidate cryogenic insulations, bonded to appropriate substrates, to experimental simulation of 50 complete mission mechanical and thermal load cycles for a representative reusable launch vehicle during tank fill, launch, ascent, and entry. The test conditions included: time-varying tank internal wall temperatures (for simulation of cryogenic containment, as low as -423F for liquid hydrogen and -320F for liquid oxygen), and insulation surface temperatures (as high as 400F during simulation of entry heating conditions), with simultaneous time-varying application of uniaxial tension loads representative of tank hoop loads. These tests validated the selection of the cryogenic tank insulation materials to be used on the X-33.

Langley-developed fiber-optic sensors will be used to monitor the flight thermal and structural performance of the X-33's liquid oxygen and hydrogen tanks, and their cryogenic insulation. Distributed fiber-optic sensors will measure temperatures on the liquid oxygen tank, and both temperatures and strain on one of the two liquid hydrogen tanks. The liquid hydrogen tank will also be equipped with fiber-optic sensors for hydrogen leak detection, as well as acoustic emission sensors for detection of structural anomalies that might occur during tank pressurization cycles. The fiber-optic strain measurement technology has already been applied in tests of a large-scale composite hydro-

gen tank (figure 36), which was built and tested as part of the X-33 ground technology demonstration program.

X-34—Langley has been fully responsible, in its partnership with Orbital Sciences Corporation, for definition of the aerodynamic performance, and stability and control characteristics of the X-34 over its entire flight envelope. In 1998, wind tunnel testing was performed in the 14x22-Foot Subsonic Tunnel to define the vehicle's low-speed aerodynamic characteristics, including the effects of ground proximity, applicable to the approach and landing phase of flight; and in the 20-Inch Mach 6 Tunnel, for definition of the vehicle's hypersonic flight characteristics (figure 37). The results of these tests, and others previously conducted in the 16-Foot Transonic and Unitary Plan Wind Tunnels, for determination of transonic and supersonic aerodynamics, respectively, provided the basis for generation of the X-34 flight aerodynamic databook. That comprehensive flight databook was delivered to Orbital in the Fall of 1998, for use in development of the vehicle's flight control system software.

Wind tunnel aerodynamic performance data are normally obtained on rigid metal models, with wings and control surfaces which do not "flex" as a result of the aerodynamic pressure loads imposed upon them. Since real flight vehicle structures can and do flex under load, a computational study was conducted to determine the potential for aeroelastic effects (i.e., the

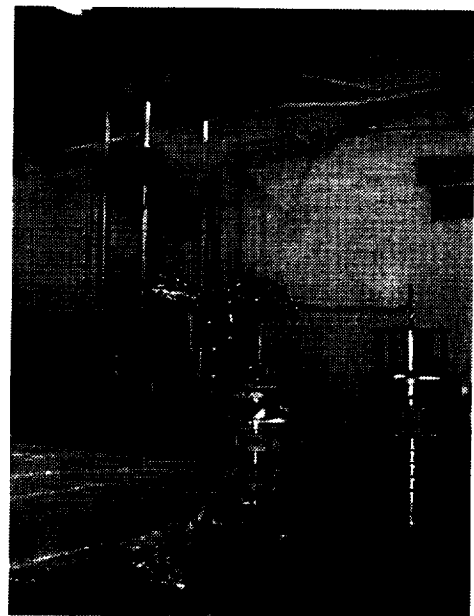


Figure 36. Structural Load Testing of Cryogenic Insulation for X-33 Hydrogen Tank.

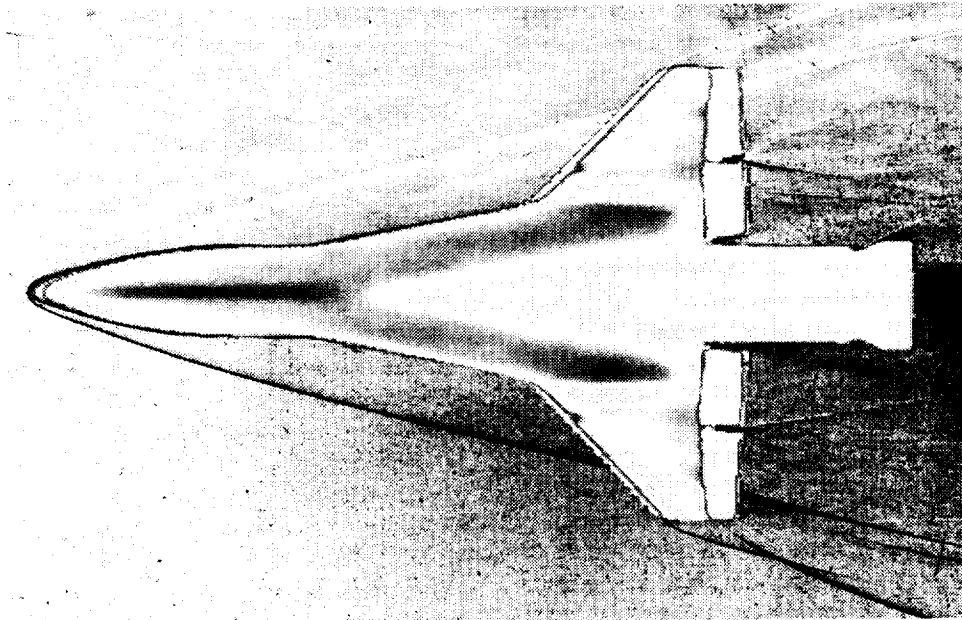


Figure 37. X-34 Flowfield and Surface Heat Transfer Data from 20-Inch Mach 6 Tunnel.
(Color version is on report website.)

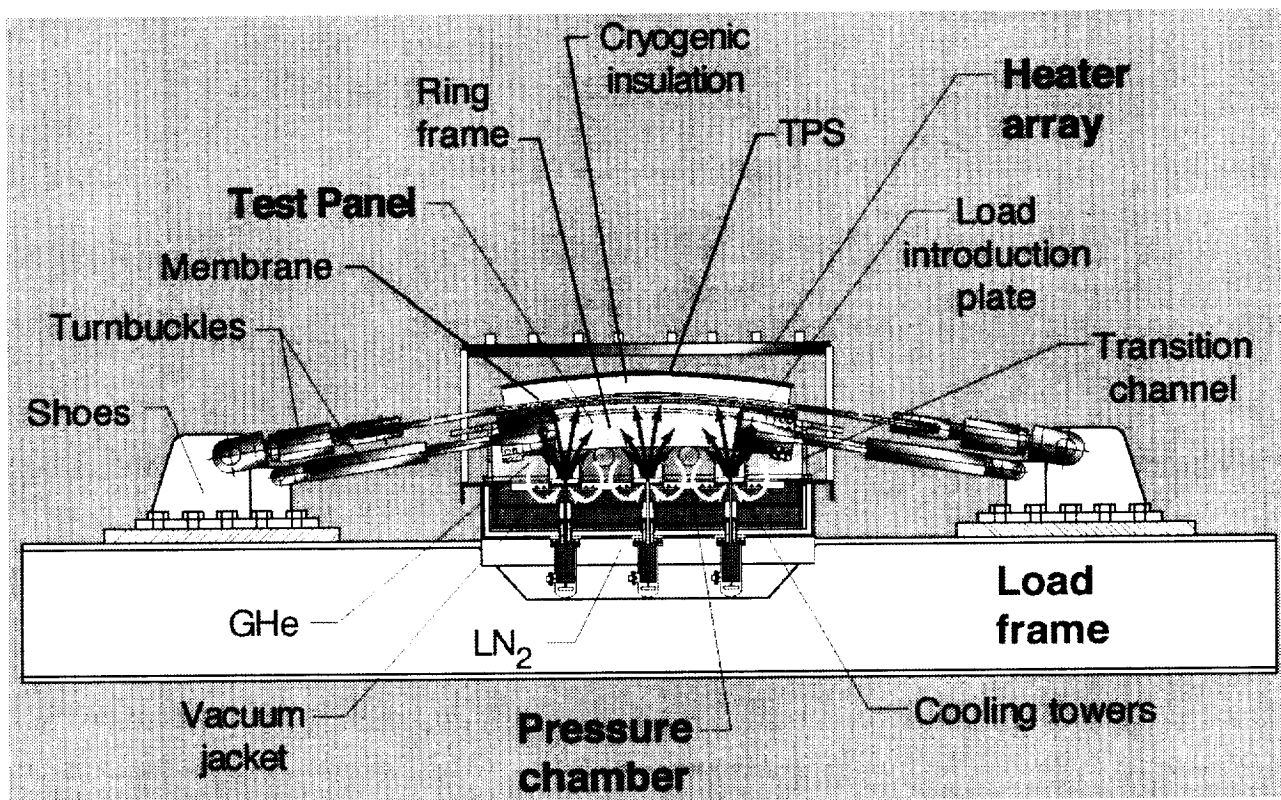


Figure 38. Cryogenic Pressure Box Facility Schematic.

effects of wing surface deflections due to aerodynamic pressure loads) on the aerodynamic characteristics of the X-34. This analysis was performed for the flight condition of peak dynamic pressure, which occurs at about Mach 1.35. The study was conducted jointly with the Structural Dynamics Research Corporation, which determined wing structural deformations, based upon wing pressure distribution information determined by Langley researchers using the computational fluid dynamic analysis tool FELISA. Aeroelastic deflections of the X-34's composite wing structure were found to be small, resulting in little change to the aerodynamic characteristics of the vehicle at this flight condition.

In addition to aerodynamic testing and analyses, extensive wind tunnel tests and computational fluid dynamic analyses have also been performed to define the aerodynamic heating characteristics of the X-34 configuration at hypersonic speeds. This information provided the basis for design of the vehicle's thermal protection system.

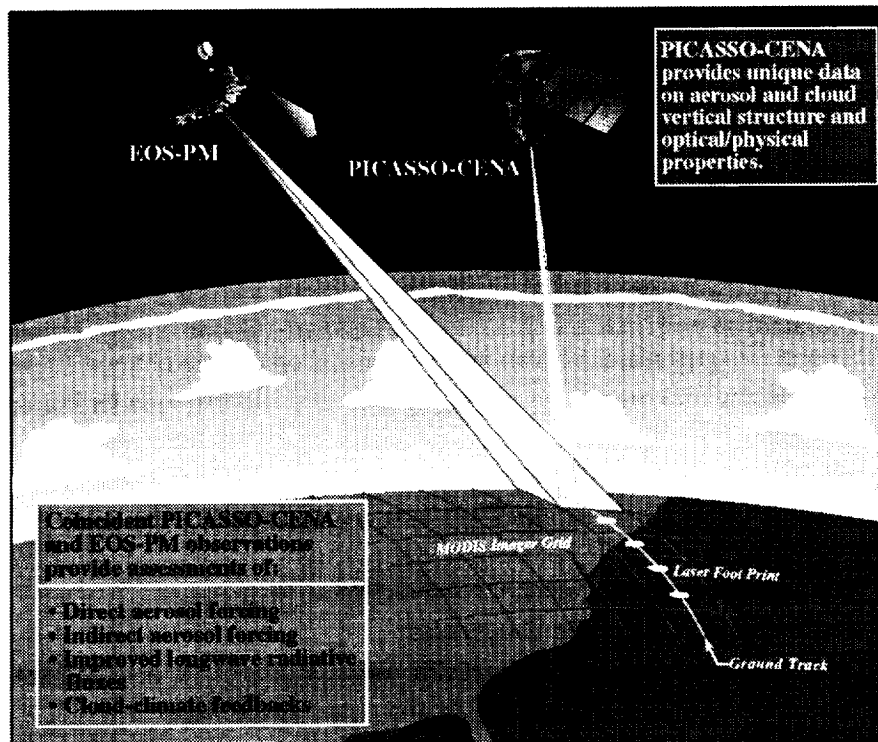
New Thermostructural Test Capability—

Advanced reusable space transportation vehicle concepts universally utilize their fuel and oxidizer tanks not only as cryogenic liquid containment vessels, but also as primary vehicle load-carrying structures. Con-

sequently, those tanks must be capable of withstanding many tens (possibly hundreds) of cycles of thermal and structural load, without degradation in their ability to perform. This is a new requirement for cryogenic tanks, as in past applications they have typically been either non-load-bearing, or not intended for multiple uses, or both. In 1998, Langley began operations of its new Cryogenic Pressure Box Facility (figure 38) that is designed to enable multi-mission, cyclic, combined loads testing of advanced reusable cryogenic tank structures. This facility provides the capability to test segments (~5x6-foot sections) of full-scale (22 to 43-foot diameter) tank structures, fully integrated with cryogenic insulation and thermal protection systems. Panels tested in the cryogenic pressure box can be simultaneously subjected to biaxial tension loads, internal pressure to 60 psig, internal temperatures as low as -423F (simulating liquid hydrogen containment) and external temperatures as high as 1000F (simulating thermal protection system entry temperature environments). This one-of-a-kind facility will enable true life-cycle (100-plus mission cycles—tank fill-and-drain, launch, ascent, and entry) testing of candidate reusable launch vehicle structures in realistic mission environments, at relatively moderate costs.

(David A. Throckmorton, d.a.throckmorton@larc.nasa.gov, 757-864-4396)

Earth Science Enterprise



PICASSO-CENA

The PICASSO-CENA mission, part of NASA's Earth System Science Pathfinder program, will study the aerosols and cloud vertical structure after launch in 2003. Langley, Hampton University, and the French Space Agency collaborated to propose the mission.

Mission

NASA's Earth Science Enterprise is dedicated to understanding the total Earth system and the effects of humans on the global environment. The Enterprise is pioneering the study of Global Change; many of the capabilities presently being developed will be needed indefinitely, and today's program is laying the foundation for long-term environment and climate monitoring and prediction.

To preserve and improve the Earth's environment for future generations, governments around the world need policies based upon the strongest possible scientific understanding. The unique vantage point of space provides information about the Earth's land, atmosphere, ice, oceans, and biota that is obtainable in no other way. In concert with the global research community, the Earth Science Enterprise is developing the understanding needed to support the complex environmental policy decisions that lie ahead.

The purposes of the Earth Science Enterprise are to:

- Increase understanding of the Earth as an integrated system
- Observe and characterize the entire Earth system using satellites, aircraft, and associated research systems
- Characterize and understand natural and human-induced change on global and regional scales with an initial emphasis on climate change
- Help identify and predict the consequences of these changes for human health and welfare
- Contribute to the creation of wise and timely environmental policy

To accomplish these purposes, the Earth Science Enterprise will employ the following strategy:

- Promote extensive international collaboration
- Cooperate with other Federal agencies
- Contribute to national and international assessments of the environment
- Strengthen environmental education and public awareness
- Make data, information, and understanding widely available through the National Information Infrastructure
- Seek or develop advanced technologies that lead to new science investigations or reduce program cost
- Transfer relevant technologies to industry in order to strengthen American economic competitiveness

The ultimate beneficiaries of the Earth Science Enterprise are the present and future generations of the people on Earth. The primary users are those who need environmental information to make decisions, especially national policy makers in the Administration and Congress and their international counterparts. The world science community also uses Earth Science Enterprise data and information—to produce assessments, forecasts, and analysis and to develop new understanding.

New Science Results from CERES

The first Clouds and the Earth's Radiant Energy System (CERES) instrument (figure 39) was launched last November 1997 on the Tropical Rainfall Measuring Mission (TRMM) spacecraft from the National Space Development Agency of Japan's Tanegashima Space Center. CERES is part of NASA's Earth Science Enterprise, a long-term research program designed to study the Earth's land, oceans, air, ice, and life as a total system.

The calibration accuracy and stability of the CERES radiometers exceed the specifications. Navigation accuracy is about 1 km, and CERES calibration is 2 to 10 times better than its predecessor, Langley's Earth Radiation Budget Experiment (ERBE). Over the first 8 months, the instrument gain demonstrated an unprecedented level of stability for Earth-viewing radiometer data. CERES radiance data (calibrated and navigated) have been in the archive since July 1998, about a factor of 4 times faster than was done for ERBE. ERBE-like monthly averaged products were archived in October 1998 at the Langley Distributed Active Archive Center (DAAC).

Combined results from CERES solar energy data and TRMM Precipitation Radar rainfall measurements have shown surprisingly low reflected solar energy for

raining tropical thunderstorm clouds. These were thought to be some of the most reflective clouds on Earth, but the CERES measurements have shown that the raining portions of these clouds have a lower reflectance than deep clouds nearby without precipitation. One hypothesis to explain this difference is that larger ice particles may be carried to levels near the cloud top in the raining clouds.

Early CERES data also indicate a real climate change of plus 4 watts per square meter in outgoing longwave flux for a 20N to 20S latitude zone between CERES in 1998 and data from the ERBE scanner period (1985–1989). Unfortunately, there is an 8-year observational gap between ERBE scanner data and CERES. However, data from the ERBE wide-field-of-view (WFOV) instrument on the Earth Radiation Budget Satellite (ERBS) spacecraft, still functioning after 14 years, indicates that this change occurred in early 1991, before the eruption of Mount Pinatubo.

The next sets of CERES instruments will be launched in 1999 on the Earth Observing System (EOS) morning (AM) platform, and in late 2000 on the EOS-PM spacecraft. The CERES investigation is poised to provide a major improvement in our understanding of the interaction between clouds, radiation, and climate.

(Bruce A. Wielicki, b.a.wielicki@larc.nasa.gov, 757-864-5683)

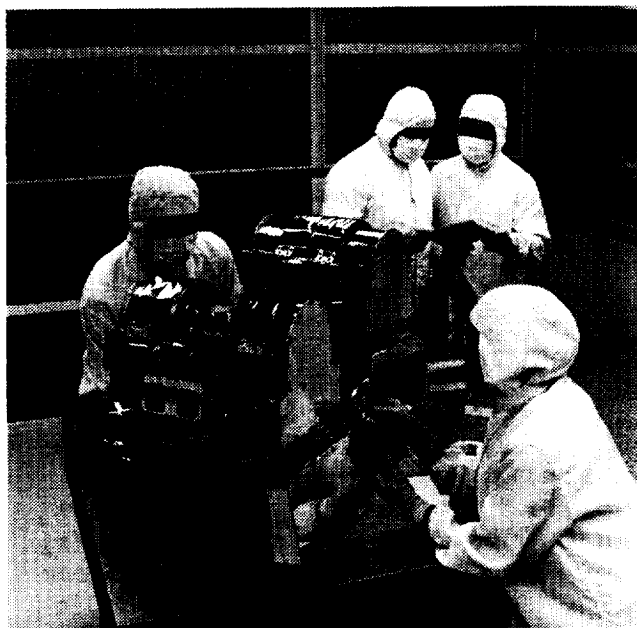


Figure 39. CERES instrument on the Tropical Rainfall Measuring Mission (TRMM) spacecraft.

CERES Data Management System Begins Operations

One of the goals of the Earth Science Enterprise is to disseminate information about the Earth system. The Clouds and Earth's Radiant Energy System (CERES) Project achieved that goal in 1998 with the public release of the first science data products from the CERES Data Management System (DMS). A seven-year development period for the CERES instrument and DMS culminated with the first launch on the joint US-Japanese Tropical Rainfall Measurement Mission (TRMM) satellite on November 27, 1997. The DMS science data processing results produced the day that CERES was turned on demonstrated the remarkable accuracy and stability of the instrument developed by Langley and TRW. First Earth-viewing measurements were collected on December 27, 1997 and quick-look results from the DMS were posted to the web by December 31 (http://asd-www.larc.nasa.gov/ceres/trmm/ceres_trmm.html). After an intensive period of validation by the CERES Science Team, the first eight months of data products were released to the public in October 1998 through

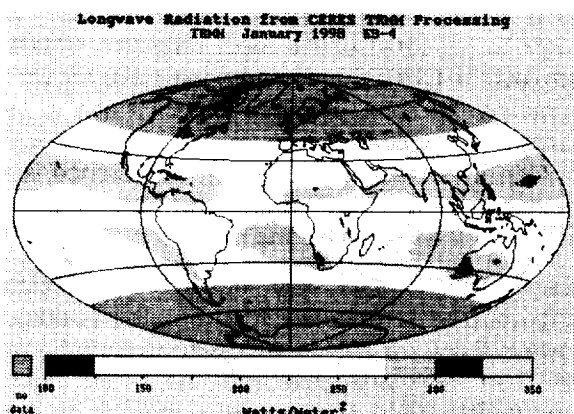


Figure 40. First monthly science data from the CERES instrument on TRMM. This figure shows longwave heat energy distributed in 2.5 degree regions around the globe for the month of January 1998. Over 800 million measurements were processed through the CERES Data Management System to produce this image. (Color version is on report website.)

the Langley Distributed Active Archive Center (<http://eosweb.larc.nasa.gov/>).

Figure 40 shows one of the parameters produced by the DMS: monthly-averaged longwave energy over regions seen from the TRMM satellite. Areas in orange and red are warmer while areas in blue and green are cooler. It is these spatial variations in energy distribution which drive our weather and climate systems. Scientists can use the information from CERES data products to help explain changes in the Earth's atmosphere such as the recent El Nino and to help predict future changes in the Earth's climate. People from universities and government organizations around the world have ordered the CERES data sets for their studies.

The CERES DMS has been operating almost continuously at Langley since the TRMM launch. It processes over 800 million measurements per month from CERES to produce nearly 50 gigabytes of daily and monthly science products for each month of operation. Preparations are now underway for an even larger amount of data from CERES instruments planned for launch on Earth Observing System satellites in 1999 and 2000. Two instruments on each satellite will more than double the amount of information collected each month. Measurements from more than one satellite help to reduce the uncertainty in the science data products.

(J. F. Kibler, jfkibler@larc.nasa.gov, 757-864-5386)

Long-Term SAGE I and II Measurements of Upper Tropospheric Aerosol Optical Depth

Measurements from 1979-1981 and 1984-1997 from the spaceborne SAGE (Stratospheric Aerosol and Gas Experiment) I and SAGE II sensors have

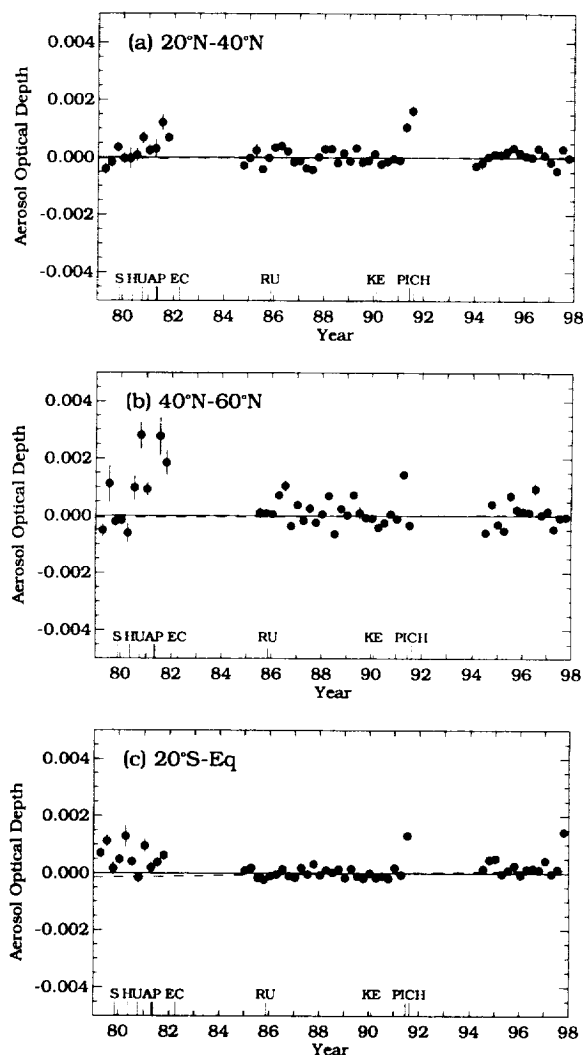


Figure 41. Residual upper tropospheric optical depth data points after the removal of volcanic aerosol effects as a function of time for (a) 20°N-40°N, (b) 40°N-60°N, and (c) 20°S-equator. Linear regression lines fitted to the residuals are shown by dashed lines. Times of volcanic eruptions affecting the stratosphere are shown by tickmarks along the abscissa: S, Soufriere; H, St. Helens; U, Ulawun; A, Alaid; P, Pagan; EC, El Chichon; RU, Ruiz; KE, Kelut; PI, Pinatubo; and CH, Cerro Hudson.

been analyzed for possible long-term changes in the aerosol optical depth of the upper troposphere. Aerosol optical depth is related to the total amount of aerosol present. It has been hypothesized that increases in aerosol production in the troposphere may affect our climate by reducing the amount of sunlight received at the Earth's surface and by changing the properties and lifetime of clouds.

A technique has been applied to the SAGE datasets to separate volcanic and surface-derived aerosol effects. This technique relies on the assumption that the upper tropospheric aerosol optical depth is linearly dependent upon the volcanic overburden in the stratosphere within a season and latitude band. Figure 41 shows the resultant upper tropospheric optical depth points after the removal of volcanic aerosol effects for 20° latitude bands between 20°S and 60°N. The two northern hemisphere latitude bands are most likely to be affected by industrial effluents, while the tropical band is most likely to be affected by biomass burning. In each panel, fitted linear regression lines are also displayed, which show an absence of any significant trend greater than 1% year⁻¹ for these regions. This is particularly so in the northern hemisphere and is to be contrasted to a background of increasing population and global industrialization over the same time period.

(Charles R. Trepte, c.r.trepte@larc.nasa.gov, 757-864-5836)

NPOESS Aircraft Sounder Test-bed-Interferometer (NAST-I)

The NAST-I was completed, and flown successfully during two major field campaigns this year. The NAST-I is a joint MIT-Lincoln Laboratory, University of Wisconsin, and NASA Langley development and implementation program, sponsored by the Integrated Program Office. NAST-I is the most sophisticated airborne remote sensing spectrometer developed to date. The instrument spatially scans the earth and atmosphere beneath the aircraft obtaining 10,000 spectral channels of information within the thermal infrared wavelength range of 3.5 to 16 microns. The signal to noise level is sufficiently high to resolve very small-scale surface and atmospheric constituent features. The three dimensional distribution of temperature and moisture is derived and this has enabled wind profiles to be observed in the horizontal displacement of fine scale water vapor features. These results serve as a basis for a NASA Langley NMP (New Millennium Program) EO-3 proposal to develop an imaging interferometer for geosynchronous satellite implementation to observe water vapor and other trace constituent

transport and to specify the four dimensional distribution of the three basic atmospheric state variables; temperature, water vapor, and wind. Future NAST-I field deployments will focus on obtaining data sets to assist the specification of instrument and algorithm characteristics for the National Polar Orbiting operational Environmental Satellite System (NPOESS) as well as provide radiance calibration and science product validation data sets for the soon to be launched EOS (Earth Observing System) platform instruments.

(William L. Smith, bill.l.smith@larc.nasa.gov, 757-864-5914)

Far Infrared Remote Sensing of Cirrus Cloud Properties

The lack of a global cirrus cloud database is a major deficiency in validating climate change models which are the basis of estimating long term climate change on our planet. Cirrus clouds are composed of ice particles that reflect incoming solar radiation and block infrared energy radiation leaving the earth. It is not known whether cirrus clouds produce a net negative or positive feedback on long-term climate change. Theory predicts that cirrus produces the largest brightness temperature changes in the Earth radiance at far infrared wavelengths. Therefore the remote sensing of far infrared Earth radiance should enable the retrieval of both cirrus thickness and particle size parameters.

Langley is a partner in an international multi-institutional effort to develop the science and technology base for infrared remote sensing of cirrus properties. Langley led the rapid development of an aircraft Fourier transform spectrometer, the Far InfraRed Sensor for Cirrus (FIRSC) for use on the Wallops T-39 Sabreliner to obtain a spectral database of cirrus radiance properties. Instrument development and fabrication began in July 1997 and was completed in March 1998. The instrument shown in figure 42 incorporated several state-of-the-art components in order to make the measurement in the far infrared spectral region at 10–70 cm⁻¹ and 80–135 cm⁻¹. The instrument was then calibrated and integrated onto the aircraft. Eleven flights were conducted from the Wallops Flight Facility in April and May of 1998. These flights coincided with satellite overpasses and correlative data gathered at radar and lidar ground facilities. The FIRSC interferometric data were accessed via internet and processed remotely by colleagues at Queen Mary and Westfield College in London and the resulting spectra were then sent to researchers at the University of Colorado for further analysis. Use of the internet allowed data to be processed in days instead of weeks.

Results from these flights (figure 43) show for the first time the dramatic effects of cirrus in the Earth far infrared radiance. The agreement of the predicted and measured cloud data in the figure validates the theory of large cirrus scattering signatures in the far infrared Earth radiance. The preliminary results were recently published in the *Journal of Applied Meteorology*. Comparisons of the cirrus thickness and ice particle size retrieved from these flights are being made to results based on experimental algorithms developed by Langley atmospheric scientists which use visible and near IR data from existing weather satellites. The information acquired from the FIRSC instrument flights will be used to design appropriate satellite instrumentation for measuring global cirrus cloud and far infrared radi-

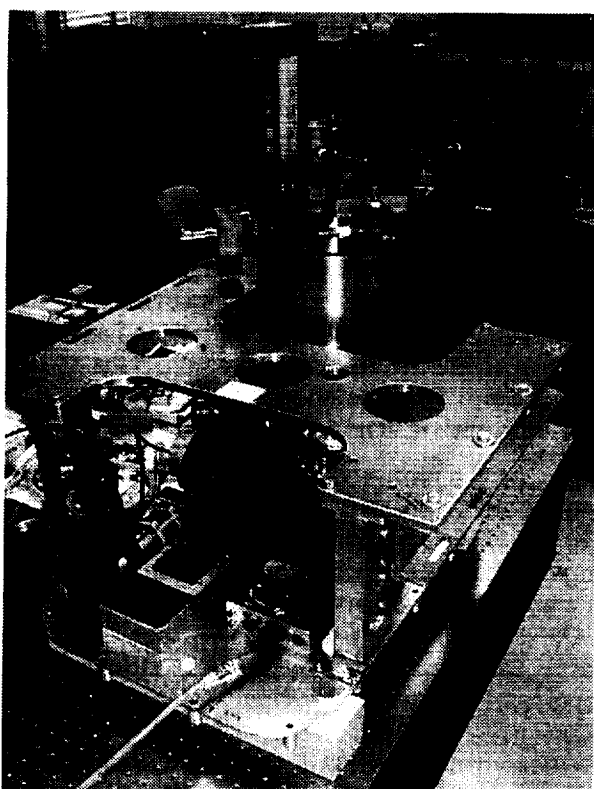


Figure 42. The FIRSC aircraft instrument is a Fourier transform spectrometer which views the upwelling Earth radiance through a small window in the aircraft cabin floor. The instrument is suspended from an attachment plate mounted to the aircraft floor to minimize vibration effects. In the foreground is the mirror drive mechanism with the FTS output directed to the cold optics and sensors which are housed in the cylindrical liquid helium cryostat.

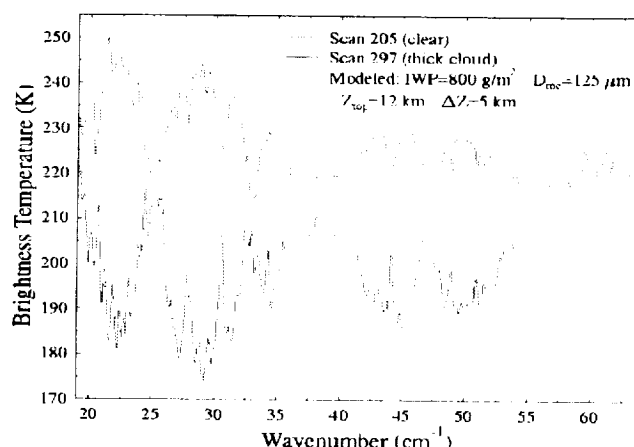


Figure 43. These two brightness temperature spectra reveal the large reduction in Earth radiance caused by thick cirrus (lower trace) relative to clear sky (upper trace) and the good agreement between the actual and modeled cloud data in the two lower traces. For this case the cirrus cloud causes a brightness temperature depression of 60 degrees Kelvin at these frequencies. This data set is fit by cirrus having an ice water path of 800 grams per square meter and average ice particle size of 125 microns. (Color version is on report website.)

ation parameters. This kind of data, retrieved on a global basis for years at a time, will significantly improve the predictive accuracy of current climate change models and the understanding of global warming. (Ira G. Nolt, i.g.nolt@larc.nasa.gov, 757-864-1623)

Laboratory Spectroscopy of Atmospheric Molecules

One of the main goals of NASA's Earth Science Enterprise is to expand scientific knowledge and understanding of atmospheric chemistry. Numerous space-based instruments and balloon-, aircraft-, and ground-based measurement campaigns have been conducted for this purpose. Detailed knowledge of the infrared spectra of carbon dioxide, carbon monoxide, ozone, and other atmospheric gases is necessary for accurate remote sensing measurements of atmospheric composition and structure. Researchers at NASA Langley and the College of William and Mary have collaborated in high-resolution laboratory spectroscopic studies of absorption lines of carbon dioxide at wavelengths near 3 micrometers to precisely deter-

mine the frequencies and intensities of these lines. This information was important to the success of the HALOE experiment on the Upper Atmosphere Research Satellite (figure 44). Another study by this group examined how carbon dioxide absorption lines are broadened and their positions are shifted by increasing pressures of air or nitrogen. This information must be taken into account when the carbon dioxide bands are used for remote sensing in an environment containing these gases. A third laboratory study examined line self-broadening and pressure-induced shifts in the strongest infrared band of carbon monoxide, which is used for remote sensing of air pollution in the Earth's lower atmosphere. Analysis of laboratory data on the spectrum of ozone enriched in the oxygen-17 isotope was also completed, and this work made possible the identification of features belonging to two forms of oxygen-17 enriched ozone in high-resolution infrared spectra of the atmosphere. Four articles reporting this research have been published in the November 1998 special issue of the *Journal of Quantitative Spectroscopy and Radiative Transfer* (Vol. 60, No. 5). In addition, NASA Langley researchers have contributed to many other articles in the same journal issue.

(Mary Ann H. Smith, m.a.h.smith@larc.nasa.gov, 757-864-2701)

Remote Field Experiment Advances Toward Enabling a New Measurement and Monitoring Capability

The focus of the Gas and Aerosol Monitoring Sensorcraft (GAMS) is to make core climate measurements in a cost effective, sustainable manner through the use of new hardware and software technologies. GAMS will measure aerosols, ozone, and other trace species in the atmosphere by looking at the sun through the atmosphere, utilizing a well-established technique called solar occultation. Measurement and long term monitoring of the atmosphere will provide critical inputs to global climate and weather models. The sensorcraft, a space flight remote sensing system that does not distinguish between the instrument, which performs a remote measurement, and the spacecraft bus, which provides the operational resources needed by the instrument in orbit, integrates the resource requirements of both to minimize size, power consumption and cost. GAMS will make significant contributions to Office of Earth Science Research areas as follows: Long-Term Climate: Natural Variability and Change Research, Atmospheric Ozone Research, and Seasonal-to-Interannual Climate Variability and Prediction.

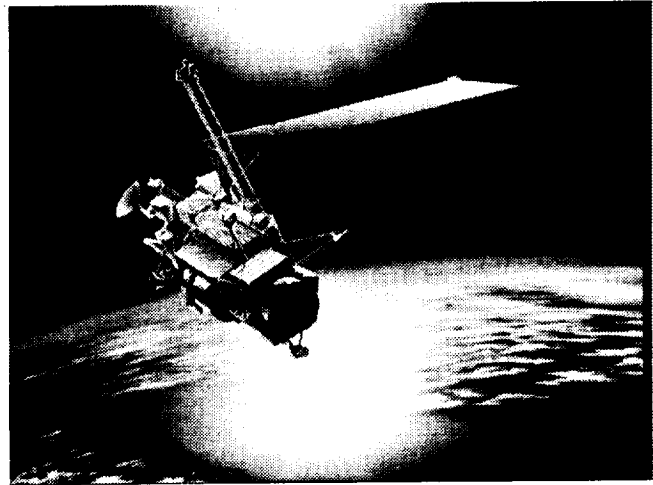


Figure 44. A painting of the Upper Atmosphere Research Satellite (UARS), a major Earth Science Enterprise mission that included Langley's HALOE among its suite of remote sensors.



Figure 45. Gas and Aerosol Monitoring Sensorcraft (GAMS) experiment team members set up for a data collection session on Mauna Loa.

A GAMS field experiment was successfully conducted (figure 45) at the Mauna Loa Observatory. The Mauna Loa Observatory is a baseline station for The Climate Monitoring and Diagnostics Laboratory (CMDL) of the National Oceanic and Atmospheric Administration (NOAA). GAMS incorporates a number of new and innovative technologies, two of which, a carbon-carbon spectrometer head and a hybrid charge coupled device (CCD) photodiode detector, were the focus of the field experiment. The GAMS experiment

utilized the high dry environment of Mauna Loa to collect the critical data required for radiometric calibration/validation of the spectrometer and development/validation of science algorithms necessary for the continued development of GAMS. Initial evaluation of the data indicates the spectrometer's (structure, optics, detector, and electronics) performance met or exceeded expectations thereby keeping the GAMS program on track to move into the next phase of development. To move into this next phase, GAMS proposed to, and was selected by, the highly competitive Instrument Incubator Program (IIP). GAMS was one of the proposals selected from the more than 100 proposals submitted to the IIP. Under the IIP the GAMS project will focus on the further development and demonstration of the hardware/software systems specific to the measurement, collection and processing of the science data. These systems incorporate several new Langley-developed technologies, the carbon-carbon spectrometer structure, the hybrid CCD photodiode detector, and the THUNDER-based piezo motors. (Clayton P. Turner, c.p.turner@larc.nasa.gov, 757-864-7103)

Digital Mammography—Remote Sensing Technology Provides Examining Room Diagnostics

Space-based instruments that researchers are using to study the atmosphere may soon have a place in the medical examination room. Researchers at NASA Langley Research Center believe that the computers and Charge Coupled Devices (CCDs) that worked so well on satellites examining the atmosphere can also be effective in mammograms for the early diagnosis of breast cancer. This transfer of technology is possible because both atmospheric studies and mammography require compact, reliable, low-power sensors and digital computers.

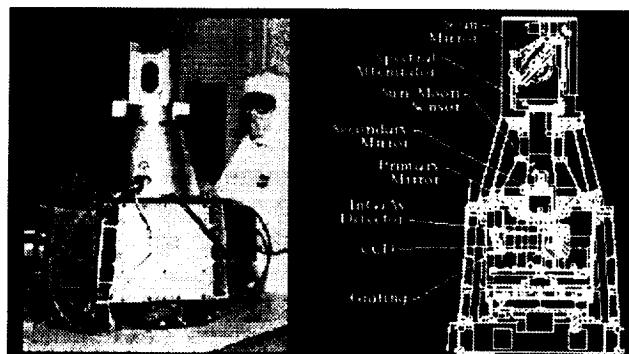


Figure 46. The SAGE III instrument (photo on left) with its CCD arrays (see schematic on right) and digital computers will monitor the Earth's ozone layer.

A CCD is a compact silicon chip built using the same technology as computer chips. You'll find CCDs in many items, like cameras, camcorders and scanners at the grocery store. The same CCD chip that can replace vacuum tubes the size of coffee cans with something the size of a postage stamp, can also replace x-ray-sensitive film used for mammography. This is done by converting x-rays into light, then into electronic signals; these signals are then changed into images and stored in a computer. In a similar way, our eyes convert light to nerve impulses that are interpreted by the brain; this is the sense we call sight. The CCD captures an image by recording the pattern created when light, or a photon, strikes the CCD surface; but the process for both is based on the same principle—converting light energy to electrical energy.

NASA Langley atmospheric scientists have used CCD technology for years in satellite-based experiments that monitor changes in the Earth's atmosphere, including natural events and human activities. The latest in the series is the Stratospheric Aerosol and Gas Experiment III (SAGE III), which will measure ozone in the stratosphere, and examine clouds, temperature, water vapor and other chemical combinations (figure 46). By monitoring ozone and atmospheric changes, researchers can determine the effects of pollution and natural events on global warming and the Earth's environment. When researchers designed a mammography unit using the CCDs, computers and scanning techniques from SAGE, they came up with one that basically compresses the breasts like conventional, film-based mammography equipment. However, conventional units use film to capture the x-ray images, so not much adjustment is possible to accommodate different tissue density (young women have dense breast tissue; older women do not). The new unit, however, based on SAGE technology, doesn't use film. It uses CCDs to capture the x-ray image electronically and transfer it directly to a computer. The computer can then assist in displaying and inspecting the image. It can even fill in any minor gaps in the image that the CCD edges might miss.

Properly exposed film mammograms reveal fine detail in the breast; in fact, some have even detected tumors as small as 0.2 mm, about the thickness of a piece of thread. How much better, though, if tumors as small as 0.1 mm could be identified clearly. That's the goal of digital mammography. Thanks to satellite technology, the researchers at NASA Langley may have devised a technique that will achieve that accuracy. If so, NASA researchers will have contributed to saving the lives of countless women using the same technology with which they monitor the atmosphere and help protect the Earth's ozone layer.

(James McAdoo, j.a.mcadoo@larc.nasa.gov, 757-864-1836)

Two-Micron Pulsed Laser Transmitter for Coherent Wind Lidar Measurements from Space

Global accurate measurements of tropospheric vector wind velocities vs. height are highly desired by NASA, NOAA, DOD, and others. These measurements would contribute to all five research areas of NASA's Earth Science Enterprise, primarily benefiting Seasonal-to-Interannual Climate Variability and Prediction. Improvements in the analysis of winds at both the global and regional scales will result in a better understanding of climate variability, as well as potential for better forecasts of such phenomena as El Niño/Southern Oscillation. Among the most notorious natural hazards are severe weather systems, which will be much better understood and predicted when the wind fields are better measured. Perhaps the most obvious impact to be made with global tropospheric wind measurements is in the area of general weather forecasting, military/commercial flight planning, military mission planning, and severe weather alerts for the public.

For over 20 years researchers have been investigating the feasibility of profiling tropospheric vector wind velocity from space with a pulsed coherent Doppler lidar. While coherent lidar has been used for decades to measure wind speed from ground and air-borne platforms, only within the past couple of years did a breakthrough in laser technology make it possible to configure a system to fly in space. To enable a first global wind measurement from space, scientists and engineers at NASA Langley Research Center created an eye-safe (2-micron wavelength) solid-state laser of sufficient power. In spring 1997, through this major breakthrough in laser technology, the team demonstrated for the first time an all solid-state, room

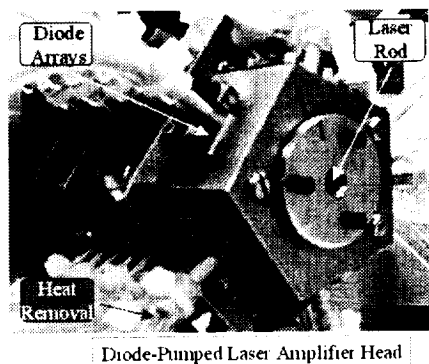


Figure 47. Amplifier Head Module for 600 mJ/10 Hz 2-micron Transmitter.



Figure 48. SPARCLE: NASA's Shuttle Coherent Doppler Wind Lidar Experiment.

temperature, diode-pumped Holmium:Thulium:YLF (Ho:Tm:YLF) laser producing an eye-safe, 2.05-micron laser output of 600 mJ at 10 Hz (figure 47). This is the highest energy ever produced and is at least an order of magnitude greater than previously achieved for a 2-micron diode-pumped laser system at room temperature.

Since 1993, a NASA team involving Marshall Space Flight Center, Langley, and JPL has been jointly developing the coherent Doppler wind lidar technology necessary for space-based measurements. The technology advancement achieved by this team allowed NASA to select, in late 1997, this technology for a space shuttle based demonstration of wind measurement in 2001 called SPace Readiness Coherent Lidar Experiment (SPARCLE) as the second Earth-orbiting mission in the agency's New Millennium Program (figure 48). In less than a year time, engineers at Langley designed and developed a fully operational diode-pumped pulsed laser transmitter breadboard for SPARCLE. In July 1998, Langley transferred the diode-pumped Ho:Tm:YLF laser technology to Coherent Technologies, Inc. (CTI; Boulder, CO) and delivered to CTI, a laser transmitter breadboard producing wind-quality 2-micron output with pulse energy of 100 mJ at 6 Hz. Langley also monitors a CTI contract for delivery of the SPARCLE flight laser transceiver by year 2000. The laser will fly in the cargo bay of the Space Shuttle at an altitude of 300 km and will attempt to measure winds from just above the surface of the Earth to a height of about 10 miles. This experiment will be a technological proof of concept mission, demonstrating the ability of the coherent Doppler wind lidar

(CDWL) technology and technique to measure winds from an orbiting platform. SPARCLE will prove the feasibility of measuring global winds to study climate change, improve hurricane predictions, and help local weatherman with the daily forecast.

The SPARCLE experiment will be a technology demonstration for a large laser facility with a significantly larger aperture deployed on a polar-orbiting weather satellite in 2004. Circling over the North and South Poles as the earth turns beneath it, a satellite could provide nearly global coverage every 12 hours. It could possibly help make a five-day forecast as reliable as a three-day forecast today. Researchers at Langley are continuing to innovate and advance the state-of-the-art pulsed laser transmitter technology in support of NASA's efforts in exploring this new frontier of space-based laser sensing of the Earth's winds. (Upendra N. Singh, u.n.singh@larc.nasa.gov, 757-864-1570)

Lidar Atmospheric Sensing Experiment (LASE)

Sponsored by the Earth Science Enterprise, LASE supports advancing and communicating scientific knowledge and understanding of the environment. The objective of LASE is to develop and demonstrate advanced water vapor DIAL technology and techniques as a precursor to the development of a spaceborne water vapor DIAL system. LASE is an airborne instrument that conducts important atmospheric investigations of water vapor, aerosols, and clouds as part of coordinated NASA field experiments. In 1998, LASE successfully deployed out of the NASA Dryden Flight Research Center (DFRC) on a NASA DC-8 aircraft during the Cloud and Moisture Experiment (CAMEX-3) Campaign (see following two highlights by Smith and Browell). One of the major objectives of the CAMEX campaign was to study hurricanes. The LASE Instrument provided invaluable real-time profiles of water vapor in addition to very useful archived data.

Alliances, partnerships, and customers include the Department of Energy, the US Department of Agriculture, National Oceanic and Atmospheric Administration, the State of Oklahoma, National Science Foundation, National Research Council of Canada, and NASA Goddard.

(Alvah S. Moore, a.s.moore@larc.nasa.gov, 757-864-7094)

Airborne Lidar Measurements of Hurricanes

An advanced lidar system called LASE (Lidar Atmospheric Sensing Experiment) flew on the NASA DC-8

aircraft during the 1998 CAMEX-3 (Convection And Moisture Experiment - 3) field experiment to investigate the large-scale characteristics of hurricanes over the Atlantic Ocean. CAMEX-3 was conducted in August and September 1998 from Patrick Air Force Base in Florida, and LASE was used to make measurements of atmospheric water vapor, aerosols and clouds in the vicinity of Hurricanes Bonnie, Danielle, Earl, and Georges. The LASE system was developed at the NASA Langley Research Center, and it uses laser light pulses transmitted both above and below the aircraft to make high-resolution profile measurements of water vapor, aerosols, and clouds in and around hurricanes. CAMEX-3 provided the first opportunity to utilize state-of-the-art lidar instrumentation to characterize the atmosphere in the vicinity of hurricanes. Water vapor and wind measurements are of particular importance because of their roles in hurricane development and tracking. These unique data are being used to help improve numerical models that are used to forecast the motion and evolution of hurricanes.

LASE measured profiles of aerosols, clouds, and water vapor when the DC-8 flew southeast of Hurricane Bonnie on August 26, 1998, just before the storm hit the East Coast of the U.S. Images of the distribution of aerosols, clouds, and water vapor, as they were observed in real-time on board the DC-8, show high concentrations of water vapor southeast of the storm as this moisture-laden air streamed into the hurricane. In addition, large changes in water vapor, aerosol, and cloud fields were seen as the DC-8 flew over the spiral rainbands of Bonnie. These LASE measurements are being used in numerical models to help understand the behavior of Hurricane Bonnie as it approached the coast.

LASE also measured profiles of water vapor, aerosols, and clouds (see figure 49) when the DC-8 flew through the eye of Hurricane Bonnie on August 26. A broken cloud field was visually observed in Bonnie's eye at this time. LASE measurements showed this eye to be quite large and revealed the precise altitudes of clouds within the eye. LASE also measured the vertical distribution of water vapor inside the eye of Bonnie during brief cloud-free periods. These LASE measurements represented the first lidar measurements of water vapor around and inside the eye of a hurricane. The combination of the LASE water vapor, aerosol, and cloud measurements with the measurements of other remote and in-situ sensors on the DC-8 is expected to improve our knowledge about hurricane development, motion, and evolution.

(Edward V. Browell, e.v.browell@larc.nasa.gov, 757-864-1273)

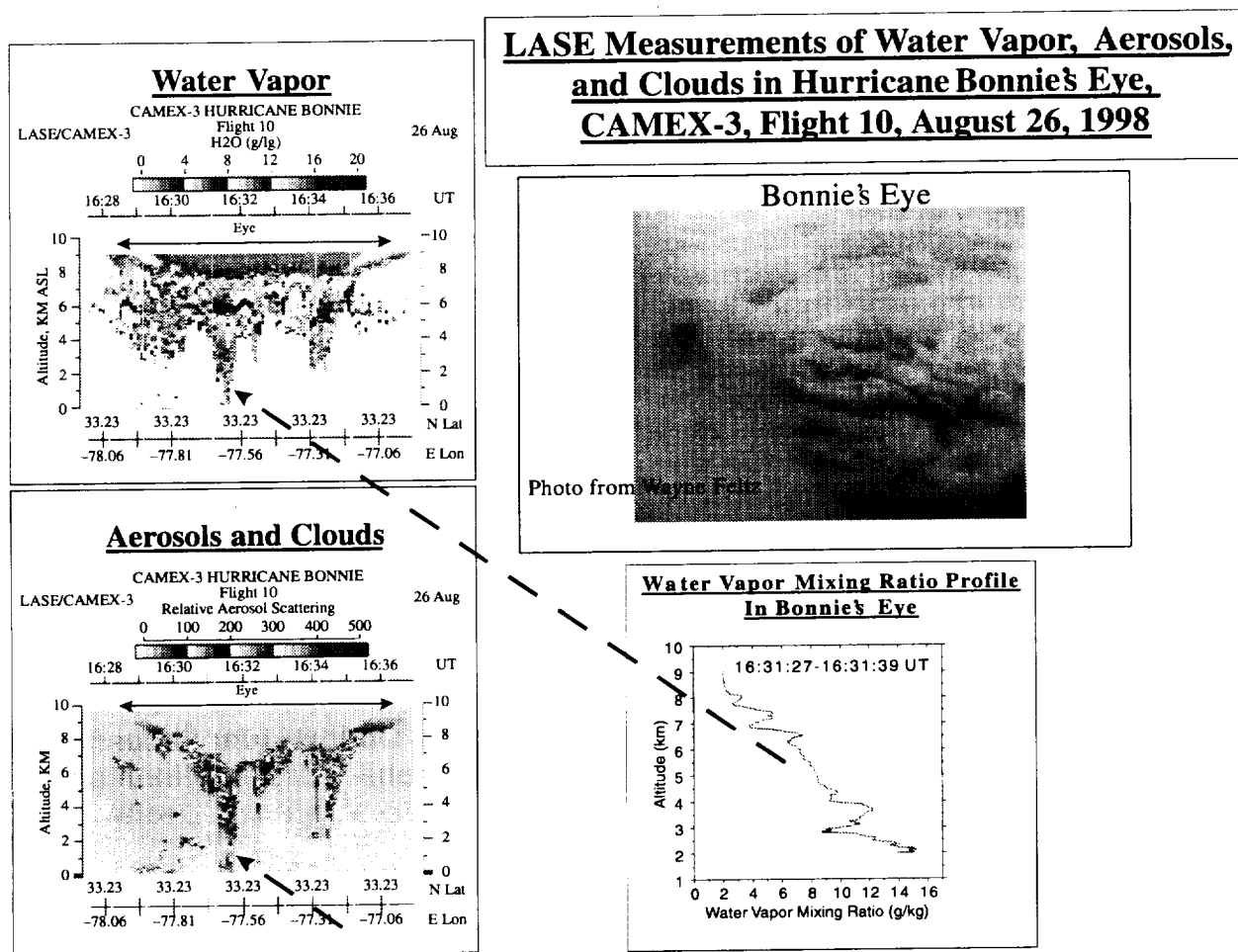


Figure 49. LASE measurements of water vapor (top left) and aerosols and clouds (bottom left) across Hurricane Bonnie's eye on August 26, 1998. The LASE water vapor profile in the eye (lower right) and photo from DC-8 of Bonnie's eye (upper right) are also shown. (Color version is on report website.)

Convection and Atmospheric Moisture Experiment (CAMEX-3)

The NPOESS Aircraft Sounder TestbedR-2 during the CAMEX-3 NAST-I observed the three-dimensional thermodynamic structure of the eye of several Hurricanes (figure 50) and provided detailed measurements of the hurricane's environment moisture flux related to storm development and the steering process.

(William L. Smith, bill.l.smith@larc.nasa.gov, 757-864-5914)

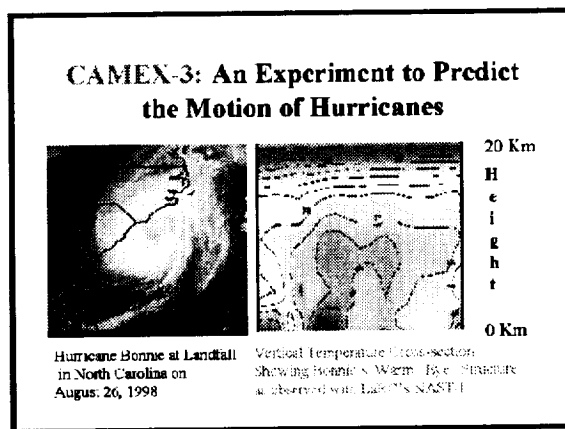


Figure 50. CAMEX-3: An Experiment to Predict the Motion of Hurricanes. (Color version is on report website.)

Increased Efficiency Laser for Remote Sensing of Water

Researchers at NASA Langley have increased the level of performance of a laser being developed for remote sensing of water vapor by nearly an order of magnitude. Remote sensing of water vapor is highly important because the concentrations of water vapor have a large influence both on short-term effects such as rainfall and possible long-term effects such as greenhouse warming. While the NASA Langley-built LASE system continues to function well on aircraft missions, a more efficient system is needed for deployment in space. In addition, atmospheric scientists needed a laser which corresponded to a stronger water vapor absorption feature than the features accessed by LASE. Consequently, a laser which operated around $0.944\text{ }\mu\text{m}$ was sought.

A common laser, Nd:YAG, could be made to operate in this region, however, two massive problems had to be overcome. Nd:YAG, which can be made to operate at $0.946\text{ }\mu\text{m}$, normally operates at $1.064\text{ }\mu\text{m}$ and has the advantage of being highly efficient at this wavelength. A primary reason for the high efficiency is that it can be directly pumped using laser diode arrays. However, the wavelength was not quite correct and the efficiency of $0.946\text{ }\mu\text{m}$ operation was quite low. With a two pronged attack, NASA Langley was able to overcome both limitations (figure 51).

Nearly an order of magnitude improvement in both the threshold and the slope efficiency was achieved. Low efficiency was attributed to amplified spontaneous emission and the quasi-four level nature of the transition. A laser beam propagating through a quasi-four level unpumped laser material suffers losses due to the absorption of the beam by the population in the lower laser level. By using a novel design, both problems were overcome. Traditional flashlamps are long thin cylinders. Consequently, laser rods also were long thin cylinders for ease of design. However, this design allowed amplified spontaneous emission to limit gain. To overcome this limitation, a short laser rod was used. Also, the entire active length of the laser rod was



Figure 51. Laboratory breadboard for solid state laser development.

pumped by the flashlamp to minimize the quasi-four level effects. When compared to the recent literature values, the threshold of this design was decreased by more than a factor of 5 while the slope efficiency was increased by more than a factor of 6. All of this was achieved while raising the operating temperature from a chilly -25°C to room temperature. Operation at room temperature is more conducive to deployment in space.

Attainment of the desired wavelength was addressed by using another novel idea, that of compositional tuning. Specifically, the chemical composition of the laser material is altered to tune the laser. Therefore, rather than using standard Nd:YAG (that is $\text{Nd}:\text{Y}_3\text{Al}_5\text{O}_{12}$) we used Nd:YAG (that is $\text{Nd}:\text{Y}_3\text{Ga}_x\text{Al}_{5-x}\text{O}_{12}$). By varying x , it was found that any wavelength in the range from 0.938 to $0.946\text{ }\mu\text{m}$ could be achieved. Clearly, any wavelength around $0.944\text{ }\mu\text{m}$ can be achieved.

(Norman P. Barnes, n.p.barnes@larc.nasa.gov, 757-864-1630)

Advanced Optical Lidar Receivers for Atmospheric Measurements of Water Vapor and Ozone

The measurement of atmospheric water vapor and ozone are of major research interest to the NASA Earth Science Enterprise and will eventually lead to a better understanding of how the atmosphere reacts to natural and human responses. Lidar has been used for many years to remotely measure the density of water vapor and ozone. A lidar system consists of a laser transmitter that sends a pulse of light into the atmosphere and a receiver that collects the laser light that has scattered from the molecules and particles in the atmosphere into the optical receiver. NASA Langley has developed advanced lidar receivers that will improve the measurement capability of its lidar systems, such as

1. A complete detector system for the differential absorption lidar (DIAL) measurement of water vapor that is no larger than an ordinary mail envelope. It consists of an advanced optical detector, a 12-bit 10-MHz waveform digitizer and an interface to a remote computer. This small device will save volume and weight when deployed in aircraft or space platforms.
2. A small, light-weight 12-inch diameter lidar telescope and detector built using carbon epoxy fiber construction. Such telescopes are mechanically rigid and insensitive to temperature changes. This system was designed to be deployed on a small unpowered airplane where weight and volume must be kept to a minimum.

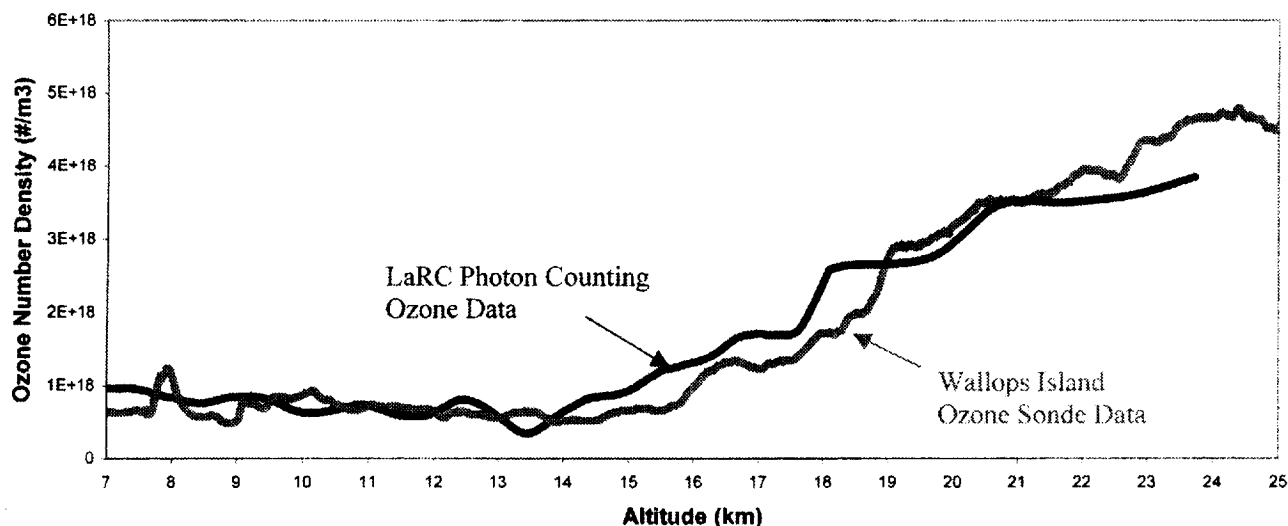


Figure 52. The measured lidar atmospheric ozone density closely follows the density as measured by the ozonesonde.

3. A lidar receiver system built to measure atmospheric ozone using the photon counting technique. Carbon epoxy fiber was used to construct the 14-inch diameter telescope and a high quantum efficiency photomultiplier was used as the optical detector. Using this receiver in a DIAL system we were able to measure the ozone density into the stratosphere to 24 km above the ground as shown in the accompanying figure 52.

(Russell De Young, r.j.deyoung@larc.nasa.gov, 757-864-1472)

Langley IMPACT 3-D Model Contribution to the Intergovernmental Panel on Climate Change Assessment of the Impact of Aviation on the Atmosphere

The environmental impact of high-speed civil transport aircraft (HSCTs) was first explored in the early 1970s with the development of European and Russian designs. With renewed commercial interest in their development, NASA and other international agencies are conducting a new round of environmental impact assessments. In support of the United Nations Intergovernmental Panel on Climate Change (IPCC) Special Report: Aviation and the Global Atmosphere, the NASA Langley IMPACT three-dimensional model was used to examine the impact of future subsonic and supersonic aircraft emissions on ozone. The model

includes a full representation of stratospheric chemistry as well as parameterizations treating the reactions occurring on polar stratospheric clouds and on sulfate particles.

The Langley model (figure 53) conducted multiple simulations using emission scenarios for a mixed fleet of subsonic and supersonic aircraft with a route structure assumed for the year 2015, as recommended by the IPCC. The simulations characterized the response of ozone to varying aircraft odd nitrogen (NO_x) emission indices, the efficiency of sulfur conversion to sulfate particles in the exhaust, and the emission of H_2O .

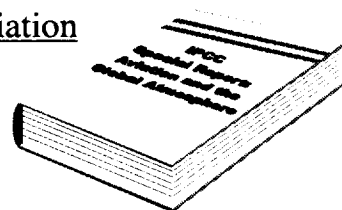
The inclusion of H_2O engine emissions significantly increased the calculated aircraft impact on ozone compared to a calculation with only NO_x emitted, particularly at low NO_x emission indices. Engine sulfur conversion to sulfate particles also led to larger ozone decreases. The calculated column ozone depletion was global in extent, extending beyond the bounds of the principal northern hemispheric transoceanic airline routes.

Recent assessments of the effects of stratospheric aircraft on the atmosphere have emphasized the need to quantify the uncertainties in model predictions. Our calculations and those of other 2-D model studies are being used to elucidate the principal sources of uncertainties.

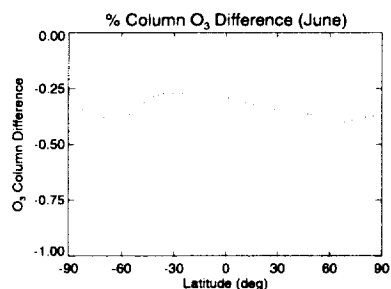
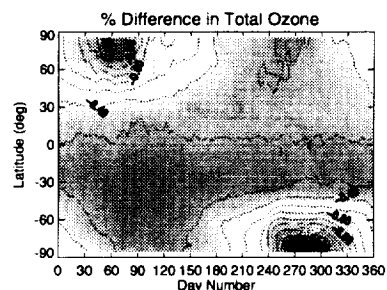
(Richard S. Eckman, r.s.eckman@larc.nasa.gov, 757-864-5822)

Atmospheric Sciences

Atmospheric Effects of Aviation



NASA Langley IMPACT 3-D Model Contribution to the Intergovernmental Panel on Climate Change (IPCC) Assessment of the Impact of Aviation on the Atmosphere



- Top panel shows column ozone depletion for a mixed supersonic/subsonic fleet relative to an all subsonic fleet for year 2015. Depletion is global in extent.
- Bottom panel shows column ozone depletion as a function of latitude in June. Maximum depletion is found at northern and southern high latitudes.

Figure 53. Langley IMPACT model calculated ozone depletion for a mixed supersonic/subsonic fleet relative to an all subsonic fleet for year 2015. (Color version is on report website.)

Retinex Image Processing and Non-linear Visual Communications

Retinex image processing, a new method for enhancing color and multi-spectral images, has been developed as a result of basic and applied research sponsored by NASA's Office of Earth Science. This general purpose automatic method achieves a high degree of visual realism by synthesizing dynamic range compression, color constancy, and color/tonal rendition. Based upon a conceptual model for human color vision proposed by Edwin Land in 1987, Langley's method has now been patented and extensively tested. It is the subject of a new commercialization program.

The retinex image enhancement method was awarded a U.S. Patent in March 1998, and has been the subject of two major journal articles, five international conference papers, and a Kidsat demonstration. A new company, TruView Imaging, has been created to commercialize the method as software products, provision of image enhancement services, and high-speed hardware boxes for video and large format

imaging applications. An example of retinex versus the original images is shown in figure 54.

The commercialization effort for 1998 includes method and software optimization to produce the best visual and computational performance for the widest range of applications, resiliency studies to understand and correct for arbitrary image manipulations prior to retinex processing, and user trials to explore the utility of the algorithm to diverse applications. In order to foster the commercialization of retinex technology, a new website was constructed to illustrate a gamut of aerospace and consumer applications:

<http://dragon.larc.nasa.gov/viplab/retinex/>

A fundamental motivation for the retinex computation is to automatically correct for spectral and spatial distortions in imaging due to illumination changes, which form an intrinsic obstacle for data analysis in remote sensing. Therefore, the potential is promising for the basic computation to be extended to automatic spectral reflectance extraction. This, in turn, is the basis for future on-board classification schemes that may significantly streamline data management and



Figure 54. Consumer color enhancement. (Color version is on report website.)

reduce costs thereby helping both NASA and commercial remote sensing missions.

In summary, these programs provide a new technology for greatly improving the visual realism and information content of color and multispectral images, for the transfer of this technology to the commercial sector, and the extension of this technology to new advances in remote sensing data analysis and basic imaging science.

(Dan Jobson, d.j.jobson@larc.nasa.gov 757-864-1521)

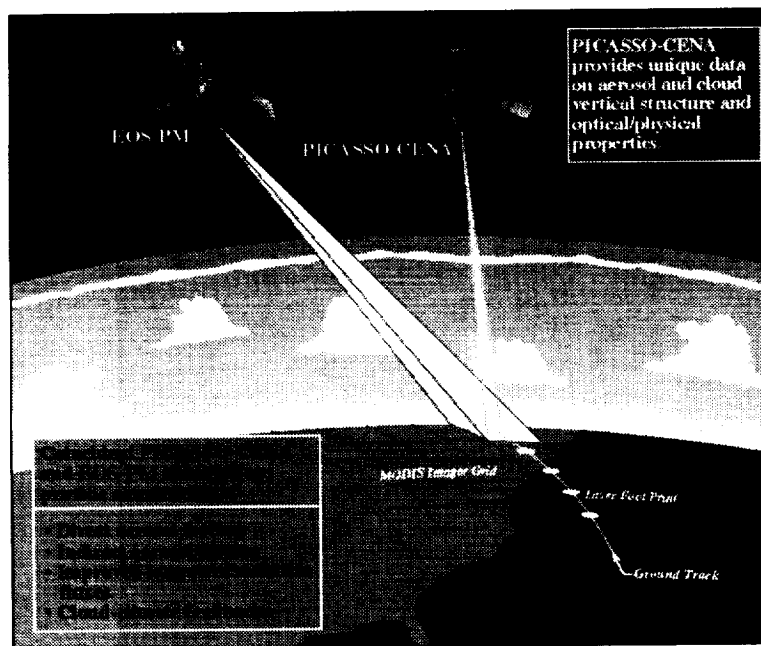
PICASSO-CENA Mission Concept

Clouds and aerosols affect the Earth's radiation budget by scattering incoming solar radiation back to space and absorbing outgoing thermal radiation. Current uncertainties in the nature and magnitude of these effects limit our understanding of the climate system and the potential for global climate change. Lidar In-space Technology Experiment (LITE) in 1994 demonstrated the usefulness of spaceborne lidar. Building on the success of LITE, PICASSO-CENA (Pathfinder Instruments for Cloud and Aerosol Space-

borne Observations - Climatologie Etendue des Nuages et des Aerosols) is a satellite mission recently selected for the NASA Earth System Science Pathfinder (ESSP) program. PICASSO-CENA will obtain new measurements of cloud and aerosol optical and physical properties necessary to improve predictions of climate change and its impacts. Key advances of PICASSO-CENA are the use of a sensitive three-channel backscatter lidar on a sun-synchronous satellite platform and the use of lidar profile data in passive retrievals.

The PICASSO-CENA payload (figure 55) consists of four instruments:

1. A two-wavelength polarization-sensitive lidar based on a Nd:YAG laser. The laser fundamental at 1064 nm is doubled to 532 nm. The components of the return beam polarized parallel and perpendicular to the outgoing linearly polarized beam are detected separately. Measurement of the depolarization of the return beam allows the discrimination of the phase of cloud particles, an important factor in determining the radiative effects of cloud. Two-wavelength aerosol data provides important information on aerosol particle size.



- One spacecraft with four science Instruments
 - Lidar
 - O₂ A-Band Spectrometer
 - Wide Field Camera
 - IR Imager
- SELV II-B Class Launch Vehicle
- Launch February 2003
- 705 km Sun synchronous orbit
 - Ascending nodal crossing beginning at 1410 precessing to 1250 after 3 years
- Formation flying (± 6 min) with EOS-PM
 - Coincident measurements with
 - MODIS, CERES, AIRS
- Mission duration: 3 years

Figure 55. PICASSO-CENA adds unique vertical profile observations to the EOS PM measurement suite.

2. A near-infrared spectrometer providing calibrated measurements of reflected sunlight over the oxygen A-band (near 765 nm) at a spectral resolution of 0.5 cm⁻¹. Information on aerosol and cloud scattering and absorption properties is embedded in these spectra. High spectral resolution data, when aided by lidar profile information, allows more accurate retrievals of cloud and aerosol optical depth as well as particle absorption and angular scattering characteristics.

3. An imaging infrared radiometer providing calibrated infrared radiances at two wavelengths in the thermal infrared window region, optimized for retrievals of cirrus particle size. Radiometer retrievals of cloud emissivity and particle size are improved by unambiguous cloud layer heights provided by the lidar.

4. A high spatial resolution camera covering the 620 nm to 670 nm wavelength region with 250 meter IFOV. This imagery provides an assessment of atmo-

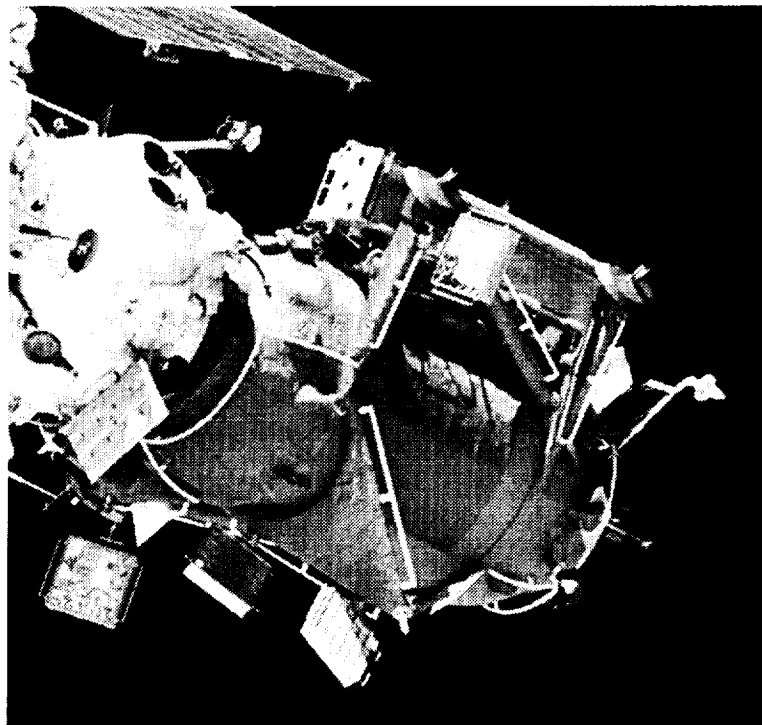
spheric homogeneity over the ABS footprint, a means for highly accurate spatial registration between PICASSO-CENA and EOS-PM, and meteorological context.

Lidar data will provide vertical profiles of aerosols and clouds. Data from the three passive instruments will be combined with lidar data to provide vertically resolved optical and physical properties of aerosols and clouds. PICASSO-CENA will fly in near formation with the already planned EOS-PM satellite to provide a coincident set of data on aerosol and cloud properties, radiative fluxes, and atmospheric state essential for accurate quantification of aerosol and cloud radiative effects.

PICASSO-CENA is being developed as a partnership between NASA and the French space agency CNES, and is planned to launch in early 2003.

(David M. Winker, d.m.winker@larc.nasa.gov 757-864-6747)

Human Exploration and Development of Space Enterprise



Mir Environmental Effects Payload (MEEP)

MEEP consists of a family of four science experiments; the Passive Experiment Carrier (PEC), the Polished Plate MicroMeteoroid and Debris (PPMD), the Passive Optical Sample Assembly I and II, and the Orbital Debris Collector (ODC), which are deployed on a common carrier.

Mission

To open the Space frontier by exploring, using and enabling the development of Space and to expand the human experience into the far reaches of Space.

Purpose

To improve the quality of life on Earth, to inspire and motivate our citizens, and to bind people together.

Goals

- Prepare to conduct human missions of exploration to planetary and other bodies in the solar system;
- Use the environment of space to expand scientific knowledge;
- Provide safe and affordable human access to space, establish a human presence in space, and share the human experience of being in space; and
- Enable the commercial development of space and share HEDS knowledge, technologies, and assets that promise to enhance the quality of life on Earth.

Enhanced Dynamic Loads Sensors (EDLS)

EDLS is a crew motion force measurement experiment that is designed to obtain a statistical understanding of the impact crews will have on the microgravity environment of the International Space Station (ISS). The primary purpose of EDLS is to provide the ISS design engineers with the force and moment range and frequency content of crew motion during the normal performance of duties on long-duration missions. The secondary purpose is to quantify crew adaptation (learning curve) to a micro-gravity environment. Specific flight objectives include the high-resolution measurement of crew forces and torque transmitted to the Mir Space Station through Intra-Vehicular restraints (handholds and foot restraints) in multiple high activity work areas, and the periodic measurement of crew forces employed in the conduct of repeated, prescribed motions. EDLS was successfully installed on the Russian Mir/Priroda Module in February 1997. Data was retrieved in May 1997, on STS-84 and is currently being analyzed. The EDLS hardware was returned in January 1998 on STS-89. Alliances, partnerships, and users include the Office of Space Flight, Russian Space Agency, and the Massachusetts Institute of Technology.

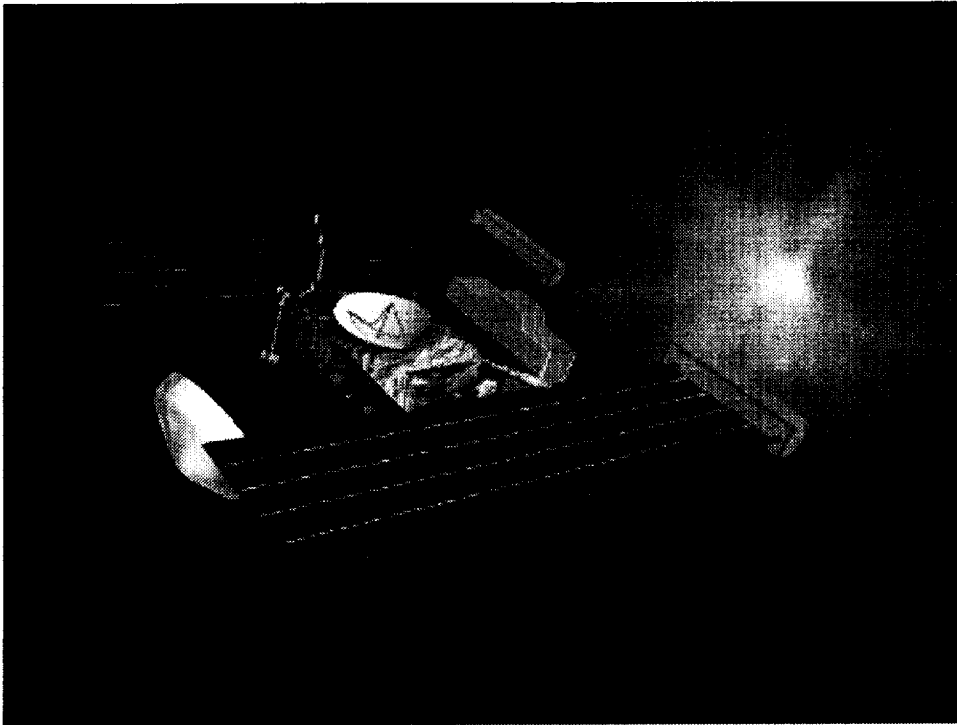
(John C. Fedors, j.c.fedors@larc.nasa.gov, 757-864-3771)

Mir Environmental Effects Payload (MEEP)

MEEP consists of a family of four science experiments, which are deployed on a common carrier. The Passive Experiment Carriers (PEC) are designed to provide a common carrier for the MEEP environmental risk mitigation experiments and provide a common interface to the Shuttle and the Russian Mir. The Polished Plate MicroMeteoroid and Debris (PPMD) is designed to assess and characterize the natural MicroMeteoroid and the man-made debris environment in the Mir orbit. The Passive Optical Sample Assemblies I and II are designed to assess the magnitude of molecular contamination on the ISS candidate critical surfaces and quantify the performance and degradation rate of candidate/baseline ISS exterior surface materials. The Orbital Debris Collector (ODC) is designed to capture hypervelocity particles in the Mir environment and return them to earth to determine their composition. MEEP was successfully launched and deployed in March of 1996, on STS-76, and returned to earth in October of 1997 on STS-86 for analysis. Partners and users include the NASA Office of Space Flight, Russian Space Agency, Boeing, and NASA Marshall Space Flight Center.

(Greg Stover, g.stover@larc.nasa.gov, 757-864-7097)

Space Science Enterprise



Stardust

Stardust is the fourth NASA Discovery class mission, and will be the first mission to return samples from a comet (Wild-2). NASA Langley played a major role in the definition of the entry, descent, and landing sequence of the Stardust sample return capsule.

Mission

- Solve Mysteries of the Universe
- Explore the Solar System
- Discover Planets Around Other Stars
- Search for Life Beyond Earth

Enterprise Goals

1. Establish a virtual presence throughout the solar system, and probe deeper into the mysteries of the Universe and life on Earth and beyond.
2. Pursue space science programs that enable and are enabled by future human exploration beyond low-Earth orbit.
3. Develop and utilize revolutionary technologies for missions impossible in prior decades.
4. Contribute measurably to achieving the science, mathematics, and technology education goals of our Nation, and share widely the excitement and inspiration of our missions and discoveries.

Science Goals

1. Understand how structure in our Universe (e.g., clusters of galaxies) emerged from the Big Bang.
2. Test physical theories and reveal new phenomena throughout the Universe, especially through the investigation of extreme environments.
3. Understand how both dark and luminous matter determine the geometry and fate of the Universe.
4. Understand the dynamical and chemical evolution of galaxies and stars and the exchange of matter and energy among stars and the interstellar medium.
5. Understand how stars and planetary systems form together.
6. Understand the nature and history of our Solar System, and what makes Earth similar to and different from its planetary neighbors.
7. Understand mechanisms of long- and short-term solar variability, and the specific processes by which Earth and other planets respond.
8. Understand the origin and evolution of life on Earth.
9. Understand the external forces, including comet and asteroid impacts, that affect life and the habitability of Earth.
10. Identify locales and resources for future human habitation within the solar system.
11. Understand how life may originate and persist beyond Earth.

Demonstration of Advanced Low-Weight/ Low-Power Concepts for Positioning Optics in Measurement Instruments for Planetary Atmospheres

A light-weight/low-powered motor for positioning the internal moving optics in instruments for measuring the distributions of molecular gas constituents of planetary atmospheres has been down-selected by NASA Langley Research Center from four concepts developed here. The motor is currently being integrated into a redesigned moving optical platform known as a double parallelogram carriage. The original design of the carriage was produced at Goddard Space Flight Center. The merits of the motor include position and velocity feedback control, power consumption of one Watt or less, and a weight at least one order of magnitude less than motors formerly used. The motor uses a unique combination of ceramic and metal materials to produce displacement, which exceed the displacements of conventional ceramic materials by several orders of magnitude. The unique combination is called THUNDER, which stands for THin layer UNimorph DRIVER.

The combination of the motor and the carriage is called a TADPC (THUNDER-Actuated Double Parallelogram Carriage). A laboratory evaluation model of a TADPC is shown in the accompanying figure 56. The lab model is currently being used to demonstrate that the motor can drive the carriage. An envisioned refinement of the TADPC is depicted in figure 57. This refinement represents a full integration of the moving optics for a Fourier Transform Spectrometer (FTS) into the TADPC. It will use the FTS's spectral reference laser for position and velocity feedback control. The

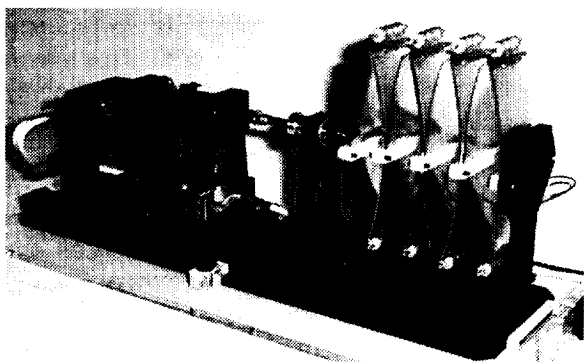


Figure 56. Photograph of the demonstration unit with the GSFC Double Parallelogram Carriage being driven by the LaRC-developed THUNDER piezoelectric motor.

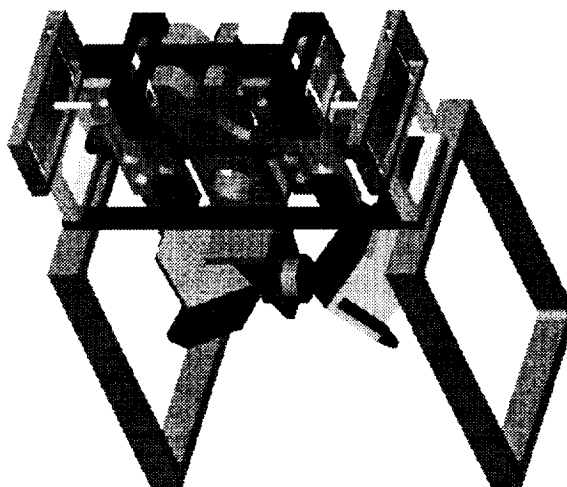


Figure 57. This graphic shows a Langley design that combines the features of the GSFC Double Parallelogram Carriage and the Langley THUNDER Piezoelectric Actuator in a mirror scan motor for compact remote sensing instruments.

FTS is a space flight instrument used to make high-resolution, broadband measurements of Earth's and other planets' atmospheric constituents.

(Dwayne E. Hinton, d.e.hinton@larc.nasa.gov, 757-864-1646)

DIGISTAR Micro Star Tracker

The DIGISTAR project seeks dramatic advances in spacecraft attitude determination based upon star sensing and pattern recognition. Building upon recent advances in image processing and pattern recognition algorithms, focal plane detectors, electro-optics, and microprocessors, this project addresses the following key objectives for spacecraft of the future: lower cost, mass and volume, increased robustness to environment-induced aging and instrument response variations, increased adaptability and autonomy via recursive self-calibration and health-monitoring on-orbit. A *smart star sensor* has been designed, a prototype tested in the laboratory, and successful end-to-end night sky experiments have been carried out. This work is being performed by Texas A&M University under the direction of Professors John L. Junkins and Thomas C. Pollock, and with informal collaborations with Dr. T. E. Strikwerda of Johns Hopkins University Applied Physics Laboratory, and Dr. Daniele Mortari of the University of Rome. Two Ph.D. graduate research assistants G. Ju and H. Kim, have made very significant contributions to the project.

Principal Investigators: *T.C. Pollock, J.L. Jenkins*Research Assistants: *G. Ju, H. Kim*

Texas A&M University

- A Micro-Star Tracker for Micro-Spacecraft
- A *Smart Sensor* which is self-calibrating and outputs attitude, not image data

- We are Striving for Significant Advances:

Low Power	Low Weight
Low Cost	High Frame Rate
Intermediate Accuracy	Modularity

- First year objectives:

- Establish Basic Design Approach
- Complete Conceptual Design of DIGISTAR - I
 - Utilize COTS Camera head, CCD array & computer
 - Develop custom lens, shutter, & structure
 - Develop Software Prototype for Operating the Camera, Centroiding/Filtering of Star Image Data, Star Pattern Identification, Star Catalog Access, and Spacecraft Attitude Determination
- Validate the Prototype System via Night Sky Imaging

- Establish Insight Necessary to Design Flight Test Version of the System circa 2001.

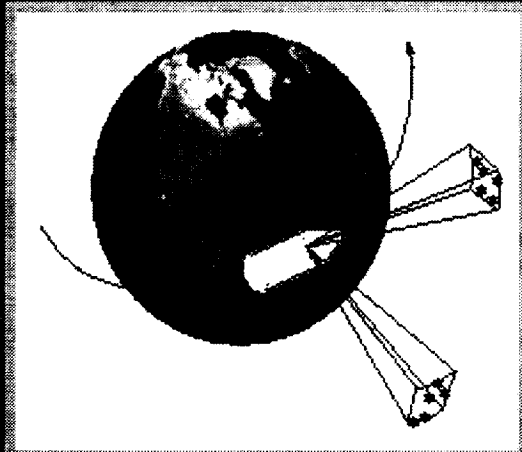


Figure 58. DIGISTAR: A Low Cost Star Tracker.

Langley Research Center is integrating this sensor concept into an overall design for a novel microsat attitude determination and control system for the Gas and Aerosol Monitoring Sensorcraft (GAMS) and Fourier Transform Spectrometer Sensorcraft (FTS) programs. In figure 58, note that the main objectives are to develop a third generation star tracker that is at once smaller, lighter, more robust, and less expensive. These simultaneous objectives are enabled by several basic advances recently made in the electronics, electro-optics, computers, and algorithms capable of robust high speed image processing, pattern recognition, and attitude determination. The DIGISTAR project is addressed to refining the algorithms, integrating COTS (Commercial Off The Shelf) hardware, and end-to-end demonstration of the validity of the overall concept. The mass budget for DIGISTAR is 1kg, and the production cost of the sensor is targeted at \$25,000, which represents better than one order of magnitude reduction in cost. The star pattern recognition and attitude determination algorithms are extensions of algorithms developed since the early 1980s by Jenkins, Strikwerda, and Mortari. Related algorithms have been successfully flown on-orbit over the past five years (e.g. Clementine, NEAR, and MSX spacecraft).

A key innovation in DIGISTAR is the development of an approach for recursive on-orbit self-calibration, based upon operating upon saved residuals from several hundred measured star image centroids versus the simulated image coordinates with the best attitude estimate and a priori calibration. Our studies indicate the systematic components of these residuals contain sufficient information, and the computational burden is within on-board computing constraints, to recursively update the sensor calibration on orbit. This will very significantly advance the robustness and autonomy of the sensor in the presence of unanticipated variations over the life of a mission.

Our laboratory studies indicate that the image centroid can be routinely located to within .05 pixel, which corresponds to better than 0.001° accuracy. Our nominal 10 ms shutter speed means $0.2^\circ/\text{sec}$ angular velocity can be accommodated without significant image smear. Our night sky experiments revealed about one order of magnitude less accuracy due to atmospheric effects. Twenty-three stars were identified in one case; typically, 5 to 10 stars are identified. Obviously, the set of measured and cataloged stars seldom match due to the fact that instrument magnitude is

difficult to simulate near the threshold. We demonstrated 2°/sec angular velocity gave only modest image smear. The elapsed time to do image processing, pattern recognition, and attitude estimation is less than 30 ms of real time in a pentium class processor and further reduction appears likely, since we have not yet optimized to account for image overlap; typically over 80% of the stars in each frame will have been identified in the previous image. The results obtained during FY1998 provide a convincing validation of the essential ideas underlying the DIGISTAR concept.

(Jer-Nan Juang, j.juang@larc.nasa.gov, 757-864-4351)

Cryogenic Actuators

A major exploration program in NASA is the Origins program which seeks to learn about the origin of the universe. One of the missions in the Origins program is the Next Generation Space Telescope (NGST). As a follow-on to the Hubble Space Telescope, NGST will be a cryogenic, infrared telescope searching for red shifted stars and the origin of the universe.

Because of launch vehicle constraints, NGST will have a segmented, lightweight primary mirror that will enable it to be stowed for launch. Once on-orbit, the mirror segments will be deployed to form a nearly perfect continuous mirror surface for the telescope. Some adjustment capability for aligning the mirror segments will be built into the telescope design. These adjustments will be provided via actuators attached between the mirror and a support or backup structure. These actuators will allow for adjustments for mirror segment phasing and mirror figure correction. Additionally, actuators are used in deformable mirrors which make any final wavefront error corrections to ensure that the images detected by the telescope are of the highest quality.

As part of the NGST team, Langley has been given the lead to develop the cryogenic actuators (figure 59). Although the final design for NGST has not yet been determined, actuators with a variety of capabilities are under development based on known requirements, traceable to NGST overall mission requirements. Selected requirements are: operating temperature of

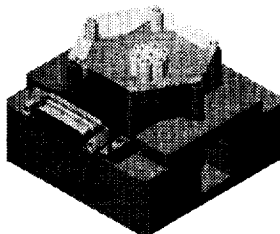
• AEH Inc.

Two-stage
stepper
motor/gear
box concept



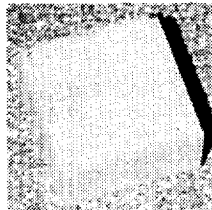
• American Superconductor

Hexagonal DM
actuator array
using cryogenic
magnetostrictive
rods with super
conducting coils



• Xinetics, Inc

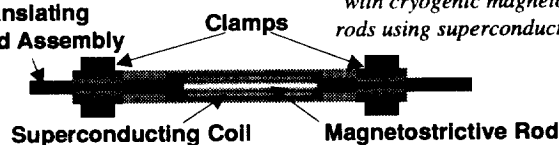
Modular DM actuator
array features rods of
single crystal or
ceramic crystallites
integrated into a
monolithic module.



• Energen, Inc

Translating
Rod Assembly

Force & position actuator driven
with cryogenic magnetostrictive
rods using superconducting coils



• Burleigh Instruments



Inchworm™ linear
motor driven with
cryogenic
piezoceramic stacks.

• NASA Langley



Linear stepper motor
using piezocrystal
stacks



Cryogenic Magnetostrictive
rod driven with a high temp.
superconductor

Figure 59. Cryogenic Actuators.

30K, resolution of 20nm, stroke of 6mm, and a "set and hold" capability without power. Five contracts for cryogenic actuator development with four companies are described in the figure. Additionally, actuator development is being leveraged through the NASA SBIR (Small Business Innovation Research) program and Langley in-house engineering staff.

A mirror shape control actuator concept being developed by Energen Inc. uses a magnetostrictive rod with a solenoid coil using a superconducting wire in the coil. By inducing a magnetic field via the solenoid coil, the magnetostrictive coil strains. The concept has two actuated clamps on opposite ends of an expanding rod. The expanding rod and two clamps use a magnetostrictive rod with a solenoid coil of superconducting wire. AEH Inc. is also developing a position control actuator that basically consists of a fine and coarse stage, each driven with a stepper motor. A force control actuator concept is being developed by Energen Inc. that incorporates a load cell that is placed between the position control actuator and the mirror.

There are two contracts to develop actuator arrays for deformable mirrors. Xinetics is developing an actuator array module using polycrystalline material and American Superconductor is developing an actuator array consisting of magnetostrictive rods.

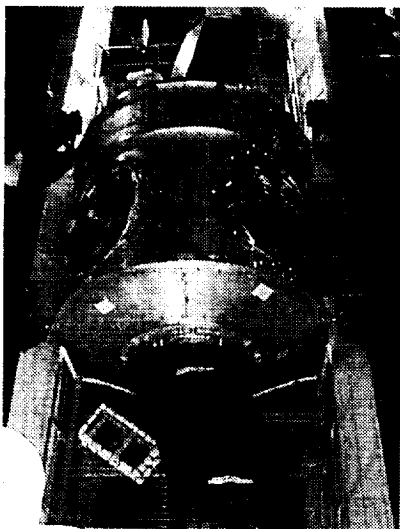
Through the SBIR program, Burleigh Instruments is developing a cryogenic Inchworm™ actuator. Langley in-house engineering and fabrication personnel are developing an inchworm-like actuator. Working with MIT and the Naval Surface Warfare Center, Langley is also developing an actuator using a magnetostrictive rod that strains due to a magnetic field applied via a persistent high temperature superconductor.

(Garrett C. Horner, g.c.horner@larc.nasa.gov, 757-864-6489)

Autonomous Modal Identification

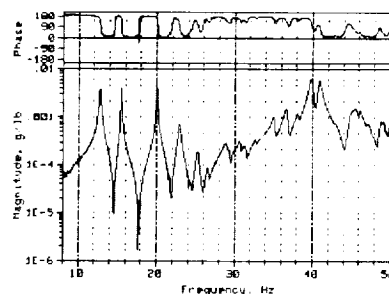
It is important to understand how spacecraft vibrate during launch and in space. Vibration levels during launch must be accurately predicted and controlled to avoid catastrophic damage. In space, excessive vibration can blur images obtained with delicately pointed

ISS Node Modal Test



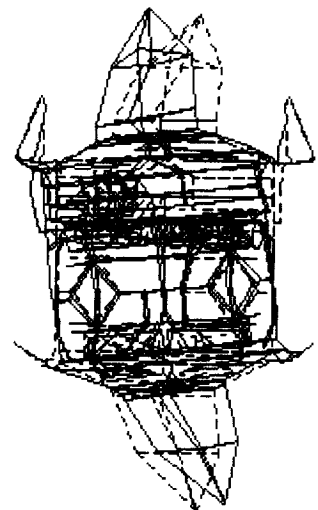
1236 Accelerometers,
46 Modes from 0-50 Hz

Frequency Response Functions



Autonomous
Identification
Algorithm

Typical Result



Frequency: 11.6 Hz
Damping: 0.3%

- Analysis time reduced from several days to approx. 7 hrs

Figure 60. Autonomous Modal Identification Algorithm Reduces Human Effort From Days to Hours.

telescopes. Excessive vibration in space can also prematurely damage important parts of the spacecraft, such as its solar arrays, due to mechanical fatigue.

To avoid these problems, the structural modal parameters of every new spacecraft are measured in the laboratory prior to launch. Modal parameters are the natural vibration frequencies, damping, and mode shapes, and they provide a concise mathematical model of the vibration characteristics. In these so-called "modal tests," hundreds of sensors (accelerometers) measure the motion of the structure due to dynamic forces applied at various locations. With large spacecraft, hundreds of megabytes of data are recorded in these tests. After these raw data are obtained, considerable effort is then necessary to identify the modal parameters using various computer programs. This data analysis effort typically takes several days or even weeks using commercially available software.

NASA Langley Research Center has developed a new modal identification technique that significantly reduces the time required for this type of vibration data analysis. The method is an autonomous version of the popular Eigensystem Realization Algorithm (ERA). This development contributes to the goal of reducing payload cost to low-earth orbit and can also reduce the cost of monitoring the health of orbiting structures.

Figure 60 shows a recent application of the new method. The structure is the "Unity" Node, which is the first U.S.-built component of the International Space Station (ISS). NASA Marshall Space Flight Center (MSFC) conducted the modal test in January 1997 using 1236 accelerometers and 3 shakers, providing one of the largest data sets ever recorded in a modal test. Using the autonomous ERA technique, the modal parameters were calculated in approximately 7 hours on a UNIX workstation, compared with several days of iterative data analysis performed by the MSFC test team. Comparison of the autonomous-ERA and MSFC results showed excellent correlation for the first 21 vibration modes up to 35 Hz. From 35 to 50 Hz, about 60 percent of 25 additional modes had excellent correlation. Natural frequencies and damping factors of most modes agreed within 0.1 Hz and 0.2 percent, respectively. Details of this work appear in the Jan.-Feb. 1999 issue of the *AIAA Journal of Guidance, Control, and Dynamics*.

(Richard S. Pappa, r.s.pappa@larc.nasa.gov, 757-864-4321)

Entry Analysis for the Stardust Comet Sample Return Capsule

The fourth of NASA's Discovery class missions is a comet sample return mission known as Stardust. It will be the first mission to return samples from a comet. The spacecraft was launched in February 1999 and will fly past the comet Wild-2. Stardust will come within 100 km of the comet nucleus and deploy a sample tray to collect cometary and interstellar dust particles. Upon Earth return in January 2006, the entry capsule (containing the comet samples) will be released from the main spacecraft (figure 61), enter the atmosphere decelerating with the aid of a parachute, and land at the Utah Test and Training Range. The entry velocity will be the highest of any Earth-returning mission. A new heat shield material made of PICA (Phenolic Impregnated Carbon Ablator) will be used to protect the Sample Return Capsule from the intense heat of reentry. The analysis of the cometary and interstellar particles is expected to yield important insights into the evolution of the sun and planets and possibly into the origins of life itself.

NASA Langley has played a major role in the definition of the entry, descent, and landing sequence of the Stardust sample return capsule. The objective of the Langley effort was to analyze and aid the design of the entry sequence, and to ascertain its robustness to off-nominal conditions during the entry. In addition, the overall landing footprint size was determined to certify the Utah Test and Training Range as the landing site. The initial activity involved validating the design con-

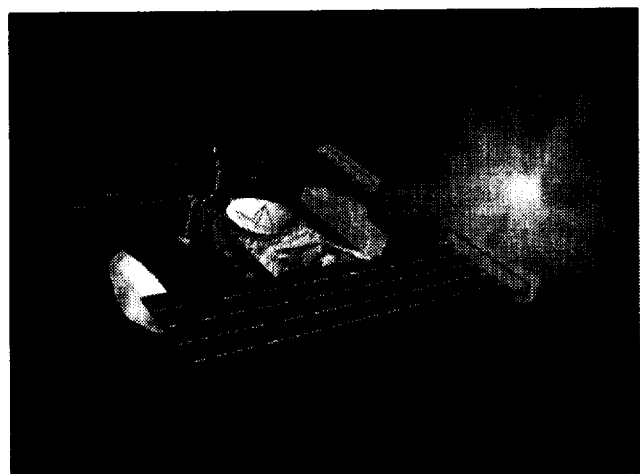


Figure 61. Stardust spacecraft sample acquisition flight configuration.

cept of the capsule entry, descent, and landing sequence. This analysis revealed two aerodynamic instabilities that produced unacceptable capsule attitude dynamics during the Earth entry. These instabilities, if not eliminated or at least suppressed, could lead to mission failure. An extensive study was launched by Langley to determine modifications which would minimize the impact of the instabilities on the mission. Based on these analyses, the entry spin rate of the capsule was increased, and a stabilizing drogue parachute was added deploying in the supersonic portion of the trajectory. As a result of the change in the parachute deployment procedures, the capsule avionics system was augmented to include a g-switch and two timers. Additionally, the higher entry spin rate required a change in the capsule separation mechanism on the main spacecraft. An analysis of this modified entry sequence shows that the attitude of the capsule during the entry is within Stardust program limits, and the corresponding landing footprint size was found to be within the boundaries of the Utah Test and Training Range.

NASA Langley has had a major impact on the Stardust entry capsule design. Through Langley's involvement in the Stardust mission, the robustness of the capsule entry sequence has been greatly enhanced. As a result, the probability of successfully returning the first comet samples to Earth has improved significantly.

(Prasun N. Desai, p.n.desai@larc.nasa.gov, 757-864-2986)

Applications of Polymeric Thin Films to the Next Generation Space Telescope

The Space Enterprise serves the human quest for knowledge and understanding of our origin, our existence, and our fate. Its mission is to solve mysteries of the universe, explore the solar system, and chart the evolution of the universe. The Next Generation Space Telescope (NGST) will be able to observe the period when the primordial seeds began to evolve into galaxies and stars we see today. Only with a NGST will we find the clues that remain hidden by time. To observe distant protogalaxies, currently unobservable by Hubble, astronomers need a much larger and cooler observatory at the near infrared range of the electromagnetic spectrum. NGST is such an observatory (figure 62). It is envisioned by scientists that the telescope would be up to a thousand times more sensitive than any existing or planned ground or space based observatory. One of the conceptual components on the NGST is a large, multi-layer sunshield deployed by inflation, to shade all parts of the spacecraft over a

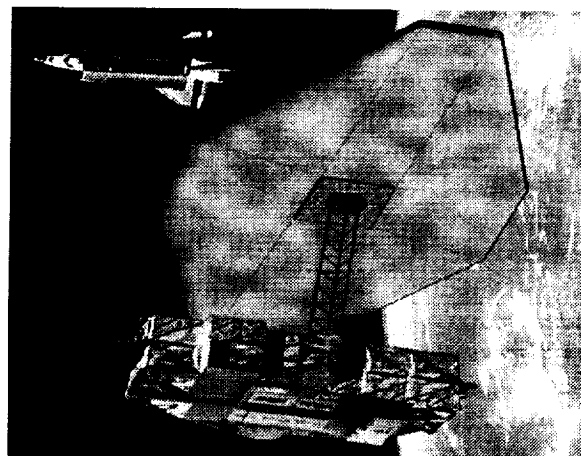


Figure 62. The Conceptual Design of the Next Generation Space Telescope (NGST).

reasonable range of pitch and roll, and maintain telescope temperatures less than -213°C (-243°C goal). Each layer of the sunshield would be approximately 30 by 14 meters. Membrane requirements include thermal and mechanical durability, stowage in a small volume (i.e. must withstand wrinkles and folds), resistance to solar winds, solar ultraviolet (UV), and radiation from solar events (i.e., soft x-rays and high energy particles), ability to withstand micrometeoroid impacts, and a ten-year lifetime. Polymeric thin films provide light weight, high strength, stiffness, dimensional stability, resistance to space environmental effects, and ability to be metallized or coated and are therefore excellent membrane candidates.

Research funded by NASA Langley's Director's Discretionary Fund enabled the synthesis, fabrication, characterization and molecular orientation of thin polyimide films to directly support sunshield and thermal shielding applications for the Next Generation Space Telescope assembly. Langley-developed polyimides were successfully stretched at ratios of 1.75 times to 4 times their original length to potentially enhance physical and mechanical properties. Dimensional stability improved with increased stretch ratio, as much as 31%. Tensile strengths increased up to 85% with increasing stretch ratio while elongations increased as much as 95%. Significant improvements in elongation were obtained with only a 2X uniaxial orientation. This information could be useful in commercial production to increase flexibility of continuous roll polyimide films. Moduli did not change significantly with stretching. Properties such as modulus and dimensional stability did not change significantly after the films had been slow cooled to cryogenic temperatures.

Additional research efforts at Langley contributed to materials development for space applications. A cooperative working relationship between Langley and Goddard Space Flight Center was initiated to identify candidate materials for the NGST sunshield. A materials property database for space durable polymers was developed (<http://spacetechnology.larc.nasa.gov:591>). Goddard Space Flight Center conducted thermal membrane testing at NASA Langley's thermal vacuum chamber to generate data which contributed to the thermal modeling confidence of closely spaced parallel layers while verifying the assumption that membrane stress levels do not measurably affect thermal performance. Other accomplishments included thermally characterizing the parasitics of the test fixture, evaluating the emittance effects of surface mounted ripstops, and providing experience with handling, folding, testing, and stressing thin filmed membranes. All of the test results confirm the primary requirements of any sunshield configuration. Langley and the Air Force Philips Lab have established a cooperative agreement with the University of Colorado to investigate the effects of wrinkling on thin film membranes for space applications. In reflective barrier or reflector applications, the film substrate and coating work together as a system. The coating provides the desired optical reflectance and absorptance properties, and the film provides structural support for the coating. In second-surface reflector applications, the optical properties of film substrate are important. When folded, both the coating and film substrate are placed in a state of stress, the actual levels of which depend upon the thickness and mechanical properties of the film and

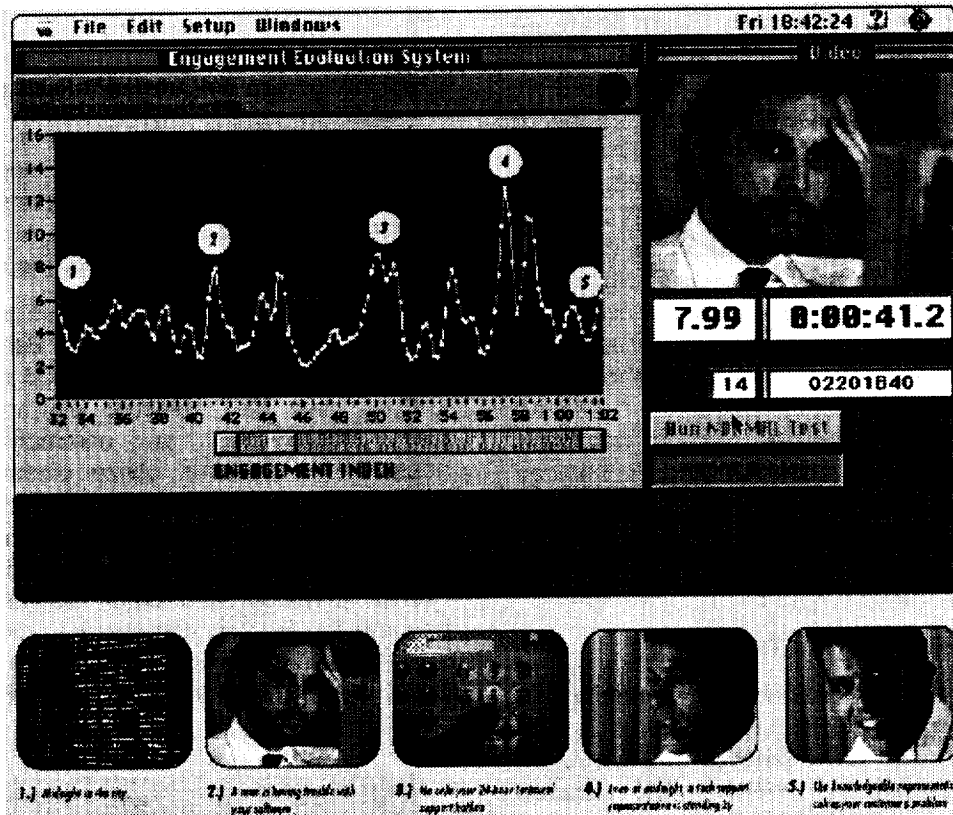
coating, and the bend radius of the fold. This folding stress can have deteriorative effects upon the coating such as complete debonding of the coating, weakening of the coating bond to the film, cracking of the coating, or over-stressing. Effects such as complete debonding and cracking of the coating are immediately noticeable. Other effects may grow in time due to synergistic effects with other environmental factors, such as thermal cycling or exposure to atomic oxygen or ultraviolet radiation.

In addition to polymers for applications on large deployable and inflatable structures, the advent of space environmentally durable polymers is also expected to lead to other high payoff technologies. These include adhesives for spacecraft components, matrix resins for structural composites, multi-layer thermal insulators (MLI), solar array substrates, antenna reflectors/collectors, membranes for inflatable structures, and thermal control coating systems.

Partners for this work included Goddard Space Flight Center, SRS Technologies (Huntsville, AL), University of Colorado at Boulder (Center for Space Construction), and Triton Systems (Chelmsford, MA). Publications include High Performance Polymer, Vol. 11, issue 1 (March 99); Fay, C. C.; Stoakley, D. M.; St. Clair, A. K. and Proceedings from the '98 43rd International SAMPE Symposium and Exhibition, May 30-June 4, 1998, Anaheim, CA, Vol. 43, Book 2, p. 1178-1189; Fay, C. C.; Stoakley, D. M.; St. Clair, A. K. This research was presented at the '98 43rd International SAMPE Symposium and Exhibition, May 30-June 4, 1998, Anaheim, CA.

(Catharine C. Fay, c.c.fay@larc.nasa.gov, 757-864-4296)

Technology Partnerships



CREW Technology

NASA Langley researchers developed a Crew Response Evaluation Window (CREW) technology to monitor human responses and evaluate the effects of pharmaceuticals, products, and medical disorders on human behavior.

Summary of Langley Technology Partnerships

NASA Langley Research Center reached out to its local community to build a strong partnership with the companies, universities and local government organizations of Hampton Roads. As the major research facility in Hampton Roads, NASA Langley Research Center plays a central role in the economic development of Hampton Roads. In an effort to maximize its positive impact on the region and to mutually benefit from its geographic proximity to the entities in Hampton Roads, NASA Langley Research Center has taken a leadership role in regional planning activities. One of the major mechanisms through which this has been accomplished is the NASA liaison position created to work with the stakeholders of Hampton Roads through the Hampton Roads Partnership. The Hampton Roads Partnership board of directors is comprised of the Mayors and Chairs of the cities and counties, the Presidents of the universities and colleges, the business leaders, and the directors of federal facilities all located within the region. This innovative approach has led to an appreciation by regional stakeholders of the benefits of NASA Langley Research Center to achieve their mutually beneficial goals of advanced technology economic development and technology commercialization.

Some examples of partnerships at NASA Langley for 1998 follow:

Intracranial Pressure Monitor Technology

Abnormally elevated intracranial pressure (ICP) occurs in 50-75% of patients with head trauma. A 95% death rate occurs when ICP increases above 200mm of Hg. The current method of monitoring ICP requires that a pressure transducer be mounted in a hole drilled in the patient's cranium. Drs. John Cantrell and Tom Yost at NASA Langley have invented a non-invasive method for the measurement of ICP which uses ultrasonics. This technique is called Constant Frequency Pulse Phase-Locked Loop (CFPPLL). It measures the minute changes in the distance from one side of the cranium to the other which result when the cranium expands due to an increase in intracranial pressure.

An exclusive license to use this patented technology was granted to Kinetic Concepts, Inc. (KCI) of San Antonio, Texas. In 1998, the commercialization of this technology passed several important milestones. First, in February a memorandum of agreement (MOA) was signed with KCI. The MOA established the respective roles of NASA and KCI in this joint development and commercialization effort and the milestones that need

to be met for timely achievement of product introduction into the medical devices market. Second, a prototype ICP instrument was built, tested and in May was delivered to KCI for testing. Clinical testing using this model is providing preliminary data on the instrument sensitivity and repeatability. Third, a technique for determining the effects of blood perfusion in subcutaneous tissue on measurement methodology was developed in August. This technique is currently being tested at Langley and will soon be tested at Ames Research Center (Ames) because non-invasive ICP measurement has applications to astronaut monitoring.

Crew Response Evaluation Window

NASA researchers developed a Crew Response Evaluation Window (CREW) technology to improve the process of monitoring human responses and to evaluate the effects of pharmaceuticals, products and medical disorders on human behavior (figure 63).

The CREW technology has been licensed to Capita Research Group, Inc. (Blue Bell, Pa.). Capita Research Group, Inc., designs and markets systems and services that measure psychological engagement, receptiveness, and communication effectiveness. These systems utilize electroencephalogram (EEG) and the CREW technology licensed under an exclusive agreement from NASA to measure electrical activity in the human brain. According to David B. Hunter, president and CEO, Capita's mission is to become the leading commercial provider of customized, high-performance systems and services, including analysis and technical support, for the real-time,

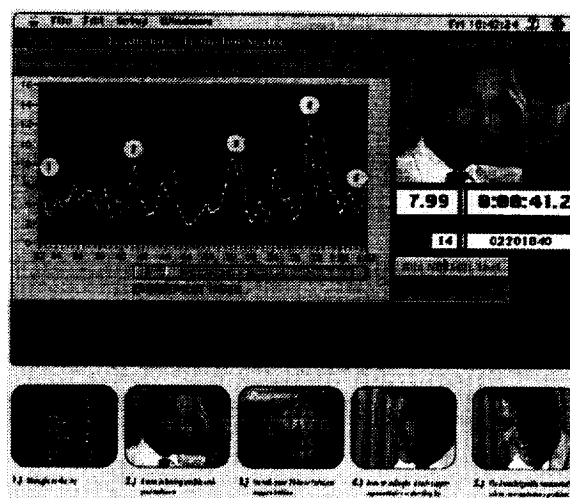


Figure 63.

objective measurement of psychological engagement for use in multiple markets.

NASA developed its biocybernetic software system as a method to evaluate automated flight deck concepts for compatibility with human capabilities. NASA scientists used the method to determine the optimum mix of allocated human and automated tasks in a cockpit. Since licensing the technology from NASA, Capita has engaged in significant research and development to further refine the suitability of the original NASA software and position it for use in media testing. Currently, the company's Engagement Index software has media-specific functionality, such as the ability to provide readings in one-fifth of a second increments, which represents a significant (x52) improvement in the reading interval capability of the original NASA software.

Advertising research has long recognized the need to develop and place commercial messages that maintain a viewer's attention, interest or involvement. With the fragmentation of traditional demographics, the proliferation of special interest groups joined globally through the Internet, and the growth of affinity marketing, the need for advertisers to optimize their media dollars through appropriate content, context and placement has never been more acute. Research to determine the efficacy of advertising and commercial placements has grown into a multibillion industry. According to Advertising Age, 1996 combined revenue from third-party media research companies exceeded \$4.0 billion in the United States and \$6.5 billion worldwide.

As an outgrowth of its preliminary marketing efforts, Capita has developed relationships with a number of prominent media, entertainment, and marketing industry leaders. "While the enthusiasm among advertising decision makers is exceptional, applications in media, education and industry seem equally compelling, and we may be seeing just the tip of the iceberg," says Hunter.

Stainless Steel Inspection

Allegheny Ludlum Corporation of Pittsburgh, PA is a producer of continuously cast stainless steel. Detailed metallographic inspection techniques are used to determine the "heat" quality of the finished steel. This labor-intensive and expensive process often results in significant and costly delays to complete and to determine the suitability of the steel for critical applications. NASA expertise, in conjunction with research/engineering contributions from Allegheny Ludlum and off-the-shelf technology from Sonix, Inc., is now being

used to perform near real-time detection of non-metallic inclusions in representative stainless steel samples.

Careful matching of detection requirements and ultrasonic transducer performance characteristics enabled researchers within NASA to develop this innovative field inspection technique. According to Bal V. Patil, Manager - Melting & Primary Operations, "we can now measure the quality of steel produced before late stage processing and shipment. This has allowed us to use a modified manufacturing process and has resulted in savings of about \$80,000 through October. In 1999, we expect the benefits to increase substantially as we intend to use the equipment to test more product. Our manufacturing cost savings could exceed \$500,000."

Bolt Tension Monitoring Technology

Ultrasonic sensors are a new and important tool for accurately measuring the strain in bolts and fasteners. In today's manufacturing environment, applying the proper clamping force is particularly important due to the use of lighter-weight materials and more precise tolerances.

Micro Control, Incorporated, an automotive inspection company, has licensed NASA Langley Research Center's ultrasonic measurement technology. Micro Control intends to combine its existing product line with the licensed technology to provide an improved method for measuring ultrasonic lengths (i.e., high degree of accuracy, fewer components, and relatively inexpensive). The technology will be used to measure the tension in bolts, fasteners, and other materials for motor vehicle and aircraft applications (figure 64).

Crack Detection Probe

An innovative crack detection probe has been developed in an effort to enhance the safety of America's aging commercial airline fleet. This technology, licensed to Foerster Instruments, Incorporated (FII), is

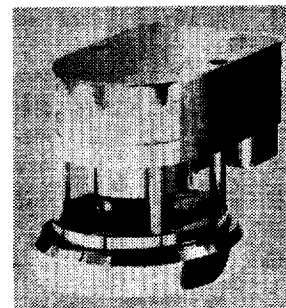


Figure 64.

Technology Partnerships

currently available for sale as the Rivet Check™ System. The system is designed to detect small cracks under installed rivets in the thin outer layers of an air-frame fuselage skin. Foerster is a leading supplier of eddy current and electromagnetic testing equipment and services both the aerospace and automotive inspection industries.

Research conducted by scientists within Langley's Nondestructive Evaluation Sciences Branch has resulted in the development of the Rotating Self-Nulling Eddy Current Probe. The unique eddy current distribution and simple flaw signature from this probe and the associated computer signal processing techniques provide a simple-to-use and highly accurate fatigue crack detector. Test results demonstrated that the probe is capable of tracing the crack tip location in real-time during fatigue load cycles.

LaRC™-CP1 and LaRC™-CP2 Inflatables For Outer Space

NASA researchers and a small business have developed lightweight structures that are revolutionizing the business of large space structures. SRS Technologies, via a NASA Space Act Agreement, has developed a business niche producing superior polymeric materials invented by NASA researchers called LaRC™-CP1 and LaRC™-CP2. The materials are being cast into large reflective elements for space communications, space power and advanced propulsion (figure 65). The use of this film material combined

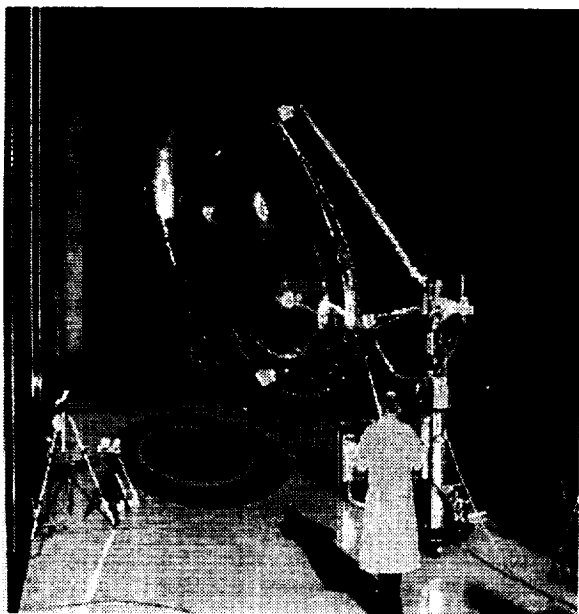


Figure 65.



Figure 66.

with the innovative collector designs is resulting in spacecraft that will enable a new market of lower cost and higher performance communication and propulsion systems. SRS Technologies in Huntsville, AL is manufacturing the NASA-developed materials under a license agreement. SRS manufactures the LaRC™-CP1 and LaRC™-CP2 as powder, resin and rolled film. For the Air Force, SRS cast NASA's polyimide into a doubly-curved film and created a sixteen-foot inflatable solar concentrator/antenna for solar thermal propulsion.

Piezoelectric Device

A NASA-developed piezoelectric device is being used by the Naval Coastal Systems in Panama City, Florida. This device is being used by Frank Downs at Coastal Systems Research to improve his design of a prototype head-contact microphone. This prototype microphone was demonstrated at the 1998 Metropolitan Fire Chiefs Conference which was attended by more than 120 fire chiefs from major U.S. cities and some foreign countries. The fire helmets (figure 66) were outfitted with the microphone and waterproof speakers and demonstrated to a live audience. This joint venture between NASA and Navy should return benefits not only to the fire fighting industry but also to the armed services.

Dual Wavelength Infrared Laser

Originally investigated in support of the Remote Sensing Program as a method of measuring the wind speed or the density of atmospheric constituents, it

was determined that it was possible to produce two or more useful wavelengths from a single laser source. Typically, a laser operates efficiently at a single wavelength, which is determined by the lasing medium present in the laser cavity. Applications that demanded more than one wavelength have, in the past, been addressed by duplicating some of the hardware, typically by building a system with multiple laser cavities. This solution greatly increases the cost, complexity, and "footprint" of a laser device. This invention provides the ability to control the lasing wavelength of a laser material without changing or adjusting any mechanical components of a laser device. Rather, this method controls wavelength by the rate, and energy level, at which the laser material is pumped. Since the wavelengths are switched electronically, rather than mechanically, this technology also allows the operator to rapidly alternate between the wavelengths. A partnership with Lantis Laser, Inc. has been established to

apply this technology to the development of a dental laser that will be capable of performing on both hard and soft tissue.

Other Accomplishments

There were 134 invention disclosures, 29 patent applications and 34 patents granted from NASA Langley Research Center Programs during 1998. There were 10 licenses executed bringing the Langley total to 70. Thirty-five Space Act Agreements were signed, with 20 representing non-aerospace industries.

There were 54 Phase I proposals and 15 Phase II Proposals selected for funding under the Small Business Innovation Research Program. The resulting contracts will stimulate technological innovation, increase the use of small businesses in meeting Langley research and development needs and help private sector commercialization of federally funded research.

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13. ABSTRACT (Maximum 200 words) Langley's mission is accomplished by performing innovative research relevant to national needs and Agency goals, transferring technology to users in a timely manner, and providing development support to other United States Government Agencies, industry, other NASA Centers, the educational community, and the local community. This report contains highlights of some of the major accomplishments and applications that have been made by Langley researchers and by our university and industry colleagues during the past year. The highlights illustrate the broad range of research and technology activities carried out by NASA Langley Research Center and the contributions of this work toward maintaining United States' leadership in aeronautics and space research. A color electronic version of this report is available at URL http://larcpubs.larc.nasa.gov/randt/1998/ . For further information about the report, contact Dennis Bushnell, Senior Scientist, Mail Stop 110, NASA Langley Research Center, Hampton, Virginia 23681-2199, (757)-864-8987.				
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